



AAiT

ADDIS ABABA INSTITUTE OF TECHNOLOGY

አዲስ አበባ ቴክኖሎጂ ኢንስቲትዩት

ADDIS ABABA UNIVERSITY

አዲስ አበባ ዩኒቨርሲቲ

Thesis Draft

**Maintenance Management Framework Development for
Competitiveness of Food and Beverage Industry: A Case Study on
Asku PLC**

BY:

Eyerusalem Mekasha

Supervisor: Kassu J. (Ph.D)

Co-Supervisor: Mr. Haileluel M.

July, 2018

Acknowledgement

First and foremost, I would like to thank the almighty God for the good health & well-being He bestowed upon me, that were necessary to complete this thesis.

I would like to express my sincere gratitude to my advisor Dr. Kassu Jilcha and co advisor Mr Hailelul Mamo for their continuous support, motivation and guidance in the overall approach of the study to complete the thesis.

I would like to express my deep appreciation to Asku PLC team for their support during data collection. I am particularly thankful to Mr. Wondemeagegn Mamo (plant manager), Mr. Binyam Dessalegn (maintenance and engineering department manager), Mr. Abreham Belete (technical expert) and Mr. Bekele Merga (quality assurance supervisor).

Last but not least, I would like to thank my family that has always encouraged and stood beside me.

Abstract

In the 20th century maintenance was taken as necessary evil in manufacturing industries. Lately maintenance is taken as a strategic factor in a company because it is directly related with reliability, availability and product quality. This has a lot to do with the competitiveness of the company in the market. Even though there are a lot of studies on developed countries in maintenance engineering and management, studies that have been conducted in Africa are limited. Similarly, in Ethiopia maintenance concept is in an infant stage and the same is true in the food and beverage industries.

In this research both theoretical and empirical studies have been performed to identify gaps on the subject matter. This has been done by studying existing maintenance frameworks on literature and studying existing company practices. As a result, the major gaps identified are that only a few number of frameworks exist and among those frameworks there is no framework developed for food and beverage industry; neither work flow system is incorporated in the frameworks nor CMMS is integrated in all the data.

An eight-block maintenance management conceptual framework has been developed for the case company in this study. The new conceptual framework addresses both theoretical and empirical gaps that are identified in this study. Validation has been conducted by presenting the study to the technical and managerial staff to obtain their expert opinion and it has been found to be fitting. The framework can be benchmarked in other bottling industries in Ethiopia. The study can also be used as an input for new researches in this area.

Contents

| | |
|---|------|
| Acknowledgement | i |
| Abstract | ii |
| List of acronyms | viii |
| Chapter 1: Introduction and Background of the Study | 1 |
| 1.1 Introduction..... | 1 |
| 1.2. Problem Statement | 2 |
| 1.3. Basic Research Question..... | 4 |
| 1.4. Objective of the Study | 4 |
| 1.4.1. General Objective | 4 |
| 1.4.2. Specific Objective..... | 5 |
| 1.5. Significance of the Study..... | 5 |
| 1.6. Scope of the study..... | 5 |
| 1.7. Expected Results from the study..... | 5 |
| 1.8. Organization of the Study | 6 |
| Chapter 2: Literature Review | 7 |
| 2.1. Definition of terms | 7 |
| 2.2. Maintenance concept globally | 8 |
| 2.3. Maintenance in Africa..... | 11 |
| 2.4. Basic Maintenance philosophies..... | 13 |
| 2.4.1. Maintenance triggers..... | 13 |
| 2.4.2. Maintenance strategies..... | 15 |
| 2.5. Maintenance management | 28 |
| 2.5.1. Maintenance management framework..... | 29 |
| 2.5.2. Maintenance Management Tools and Techniques..... | 44 |
| 2.6. Maintenance and Performance..... | 50 |
| 2.7. Maintenance performance measurement | 51 |

| | |
|--|-----|
| 2.7.1. Performance indicators, drivers and killers | 53 |
| 2.8. Maintenance in food and beverage industry | 55 |
| 2.8.1. Maintenance Challenge in Food and beverage Industry | 56 |
| 2.9. Summary and gaps from literature..... | 57 |
| Chapter 3: Research Methodology..... | 59 |
| 3.1. Introduction..... | 59 |
| 3.2. Data collection | 59 |
| 3.3. Sampling and sample size:..... | 60 |
| 3.4. Data Presentation and Analysis | 61 |
| 3.5. Research framework | 62 |
| Chapter 4: Company Profile | 65 |
| 4.1. Organizational Structure | 67 |
| Chapter 5: Data Analysis and Discussion..... | 70 |
| 5.1. Data Presentation and Analysis | 70 |
| 5.2. Results and Discussion | 84 |
| Chapter 6: Conceptual Framework of Maintenance Management | 70 |
| 6.1. Introduction..... | 88 |
| 6.2. Conceptual Framework..... | 88 |
| 6.3 Implementation procedure | 95 |
| 6.4 Validation..... | 95 |
| Chapter 7: Conclusion and Recommendation..... | 97 |
| 7.1 Conclusion | 97 |
| 7.2 Recommendation | 98 |
| Reference | 100 |
| Appendix A..... | 104 |
| Appendix B..... | 107 |

| | |
|-----------------|-----|
| Appendix C..... | 113 |
|-----------------|-----|

List of Tables

| | |
|---|----|
| Table 1.1: Production performance excluding VOS..... | 3 |
| Table 2.1: Emerging trends in maintenance (Pintelon, 2002 and Garg, 2006)..... | 10 |
| Table 2.2: Literatures of maintenance concept in Africa..... | 11 |
| Table 2.3: Classification of maintenance type based on maintenance triggers | 15 |
| Table 2.4: Leading and lagging indicator | 53 |
| Table 2.5: Problems on maintenance operation..... | 57 |
| Table 3.1: Participants for data collection with their respective position..... | 61 |
| Table 5.1: General information..... | 70 |
| Table 5.2: Maintenance strategies followed on different machines | 79 |
| Table 5.3: Condition of tools | 81 |
| Table 5.5: Blower and Filler machine..... | 83 |
| Table 6.1: Blow molding machine failure mode and effect analysis..... | 89 |

List of figures

| | |
|---|----|
| Figure 1.1: Operational Downtime | 3 |
| Figure 1.2: Technical Downtime/maintenance problem..... | 4 |
| Figure 2.1: Reviewed papers at Africa level..... | 13 |
| Figure. 2.2: Elements of Preventive Maintenance | 17 |
| Figure 2.3: Risk based maintenance framework..... | 20 |
| Figure 2.5: Framework 1 (Vanesste and van Wassenhove 1995)..... | 31 |
| Figure 2.6: Maintenance policy decision tree(Waeyenbergh and Pintelon, 2002) | 33 |
| Figure 2.7: Schematic overview of the proposed framework (Waeyenbergh and Pintelon, 2002) | 34 |
| Figure 2.8: Maintenance management framework (Marquez, 2007) | 36 |
| Figure 2.9: CIBOCOF framework (Waeyenbergh, 2009) | 37 |
| Figure 2.10: Individualized maintenance framework (Naughton and Tiernan 2012) .. | 39 |
| Figure 2.11: Maintenance management framework (Wireman, 2005)..... | 40 |
| Figure 2.12: Maintenance management framework (Hesham, 2015)..... | 40 |
| Figure 2.13: Maintenance reengineering framework (Sharma, 2013) | 42 |
| Figure 2.14: Integrated framework (Faccio et al., 2014) | 44 |
| Figure 2.15: OEE diagram (Muchiri, 2011)..... | 47 |
| Figure 3.1: Graphical representation of research methodology | 64 |
| Figure 4.1: Organizational Structure..... | 67 |
| Figure 5.1: Rate of machine performance..... | 71 |
| Figure 5.2: OEE of filler machine..... | 71 |
| Figure 5.3:OEE of Neck sleeve machine | 72 |
| Figure 5.4: OEE of labeler machine | 72 |
| Figure 5.5: OEE of packer machine..... | 73 |
| Figure 5.6: Summary of OEE trend | 74 |
| Figure 5.7: Direct participation of employees on machine maintenance..... | 75 |
| Figure 5.8: Support received during maintaining an equipment..... | 75 |
| Figure 5.9: Good communication between production and technique department | 76 |
| Figure 5.10: Maintenance of equipment as a strategic factor | 76 |
| Figure 5.11: Followed maintenance strategies..... | 77 |
| Figure 5.12: Quick response rate to repair an equipment | 77 |
| Figure 5.13: Tendency to recognize failure before it happen | 78 |

Figure 5.14: Causes of machine breakdown 79

Figure 5.15: Maintenance procedure 80

Figure 5.16: availability of proper tool 80

Figure 5.17: Training schedule and implementation 81

Figure 5.18: Training covering areas 82

Figure 5.19: Total downtime summary 83

Figure 5.20: System classification 85

Figure 6.1: Proposed workflow 92

Figure 6.2: Conceptual framework of maintenance management 94

List of acronyms

BSC- Balance score card

CBM- Condition based maintenance

CM- Corrective maintenance

CMMS- Computerized maintenance
management system

ERP- Enterprise resource planning

FMEA-Failure mode and effect analysis

FMECA- Failure mode effect and criticality
analysis

FTA- Failure tree analysis

HSE- Health, safety and environment

JIT- Just in time

KPA- Key performance area

KPI- Key performance indicator

MCDM- Multi criteria decision making

MMIS- Maintenance management
information system

OD- Operational downtime

OEE- Overall equipment effectiveness

PdM- Predictive maintenance

PI- Performance indicator

PM- Preventive maintenance

RBM- Risk based maintenance

RCA- Root cause analysis

RCM- Reliability centered maintenance

RPN- Risk probability number

TPM- Total preventive maintenance

TQM- Total quality management

TQMain- Total quality maintenance

VDM- Value driven maintenance

VOS- Valid other stoppages

Chapter 1: Introduction and Background of the Study

1.1 Introduction

The manufacturing industry has experienced an unprecedented degree of change in the last three decades, involving drastic changes in management approaches, product and process technologies, customer expectations, supplier attitudes as well as competitive behavior. In today's fast-changing marketplace, slow and steady improvements in manufacturing operations do not guarantee sustained profitability or survival of an organization. Thus, the organizations need to improve at a faster rate than their competitors if they are to become or remain leaders in the industry (Melesse and Ajit, 2012).

In recent years, industry managers have been gradually moving to the idea that maintenance can be a profit generating function rather than merely a cost center. When it comes to issues such as reliability, availability, safety, quality, and cost-effectiveness levels of plant and equipment there is no doubt that the cost of maintenance can be high and often representing a significant portion of recurrent budgets (Kym Fraser et al, 2015).

Al-Najjar (2007) stated that company's internal effectiveness is strongly influenced by the maintenance role and impact on other working areas such as production, quality, production cost, working environment, amount of work in progress and tied up capital. Many researchers have also discussed the importance of the maintenance function in the context of its role in keeping and improving availability, performance efficiency and product quality (e.g. Al-Najjar, 1996; Ris et al., 1997; Al-Najjar and Alsyouf, 2003). (Maletic et al, 2014).

Industrial systems evolve rapidly. To keep up with the changing systems and environment that the maintenance strategy needs to be reviewed periodically to increase production efficiency continuously in order to be competitive. The maintenance of production equipment is one important factor of this (Waeyenbergh and Pintelon, 2002, Salonen, 2009).

Any industry by itself has its own set of challenges. The food and beverage manufacturers probably face more hurdles. Since they are producing physical products that humans consume, there is a higher scrutiny in these industries. Therefore, manufacturers of edible products face diverse significant challenges including stringent government and international regulations, and complex equipment that can be difficult to maintain and manipulate easily.

Asku plc. is a case company in this research. The company is in the food and beverages line of business. Bottled water, carbonated soft drinks and juice are products of Asku plc.

The company data indicates that the average production performance of the past two years is around 63 %. The main reasons that hinder the company not to achieve the target are operational down time and valid other stoppages.

- Valid other stoppages are downtimes due to power interruption, political instability, unplanned line change over, and other factors that cannot be avoided or beyond plant management.
- Operational downtime can be caused by machine breakdowns or operational problems. This also includes human resource related issues such as operating machines at maximum speed by operators so as to get incentives, under staffed maintenance team, lack of maintenance employee commitment to do running and non-running inspections periodically and high turnover of machine operators

This indicates that there is a maintenance problem in the company. In addition to normal wear and deterioration, other failures may occur especially when the equipment are pushed beyond their design limits or due to operational errors. As a result, equipment downtime, quality problems, speed losses, safety hazards or environmental pollution become the obvious outcomes. All these outcomes have the potential to impact negatively the operating cost, profitability, customers' demand satisfaction, and productivity among other important performance requirements.

To ensure the plant operates at the required condition while meeting its production targets at an optimal cost, maintenance management has to make conscious decisions regarding the maintenance objectives and strategies that need to be pursued. Therefore, this study addresses the maintenance problem by developing a new maintenance management framework in order to increase the competitiveness of the company.

1.2. Problem Statement

On literature an increasingly number of companies replace the current reactive, “fire-fighting” maintenance strategy with proactive strategies (Swanson, 2001). This is also the current maintenance practice in Asku plc which hinders the company from not achieving its targets.

As per the monthly production performance report, capacity utilization of 2015/16 and 2016/17 were 59.8 % and 52.5% respectively. If we deduct valid other stoppages (VOS) or external factors the performance would become 63.2% and 64.1 %. The main reasons not to achieve the target is operational down time (OD) and valid other stoppages (VOS).

Table 1.1: Production performance excluding VOS

| Year | Plan to be produced in Hectoliters | Actual produced quantity in Hectoliters | Performance in % |
|---------|------------------------------------|---|------------------|
| 2015/16 | 996,546 | 629,817 | 63.20% |
| 2016/17 | 1,029,346 | 659,811 | 64.10% |

As shown in figure 1 and 2, based on the company’s data, 72% of the downtime arises from machine breakdown due to poor & unorganized maintenance system of the company.

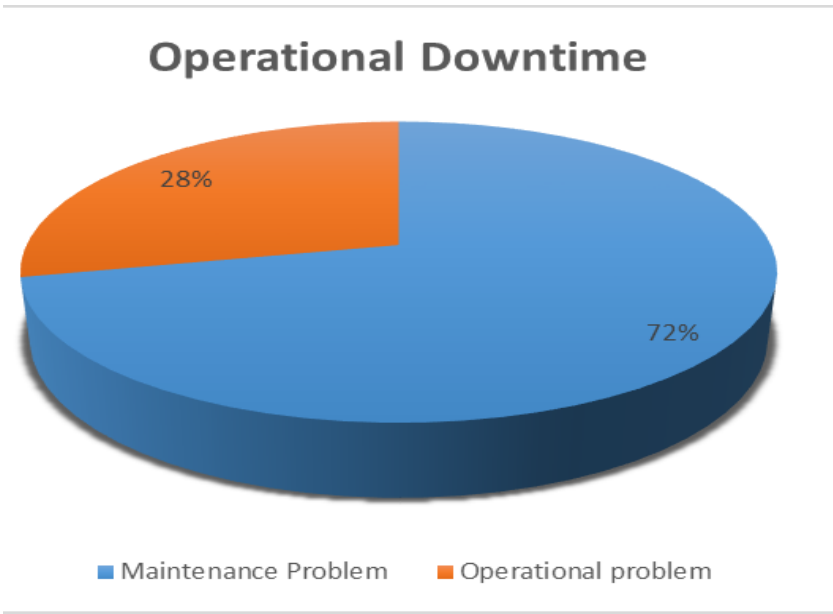


Figure 1.1: Operational Downtime

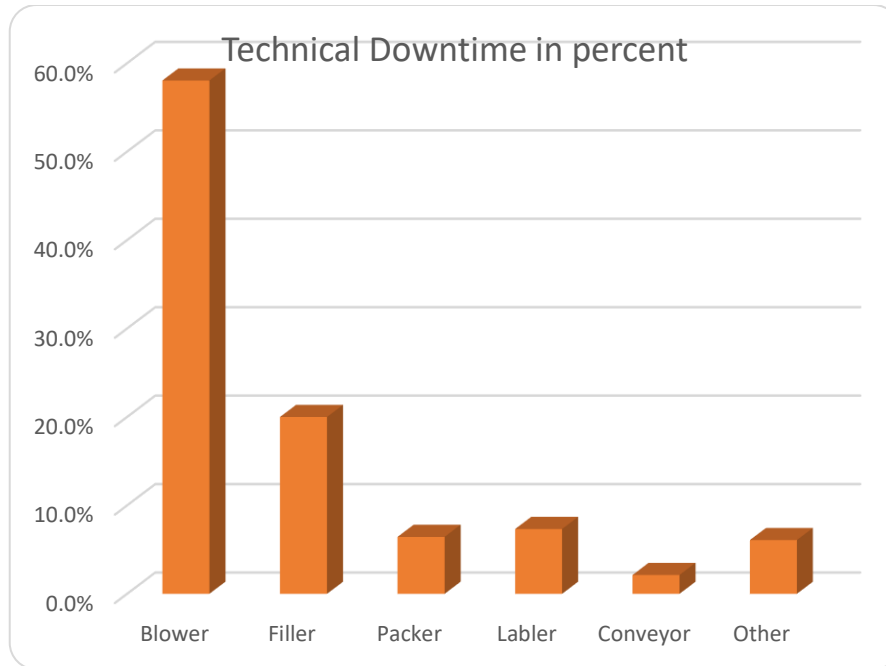


Figure 1.2: Technical Downtime/maintenance problem

This thesis will mainly focus on operational downtimes due to maintenance problem. Therefore, having a proper maintenance system will solve recurring machine breakdowns of Asku plc.

1.3. Basic Research Question

This study will answer the following questions:

- What are the existing maintenance challenges and the major problem that are affecting production performance/causing machine downtime in literature gaps?
- What are the governing maintenance management related problems or obstacles in Asku plc?
- How to improve the existing maintenance problem of Asku plc?

1.4. Objective of the Study

1.4.1. General Objective

The main objective of this thesis is to address the causes of machine breakdowns in Asku plc by developing a maintenance management framework and thereby increase the competitiveness of the company.

1.4.2. Specific Objective

- To identify existing maintenance management system and deficiencies in literature researches so as to identify the existing gaps.
- To identify existing company's case organization machine performance and maintenance culture and challenges.
- To identify major reasons for downtime in the case company.
- To develop a maintenance management conceptual framework based on the existing models.

1.5. Significance of the Study

This research result will benefit:

- Asku plc to determine major causes of machine breakdowns and to address the problems in order to maximize production performance by minimizing unnecessary hidden costs that occur due to poor maintenance management system.
- Other beverage companies by benchmarking the model.
- Other food and beverage researchers to use this paper as an input.

1.6. Scope of the study

The research focuses on case company maintenance practice, management system and any maintenance related issues. The company has two separate plants which are plant A and plant B. At plant A there are five work centers. Out of five work centers four work centers have an average of five machine centers, whereas plant B is an expansion project and is not fully functional. Therefore, this paper will be limited to the four independent work centers of plant A.

1.7. Expected Results from the study

The main expected result from this paper are: -

- Identified existing maintenance management framework gaps.
- A newly developed maintenance management framework fit for Asku plc.

1.8. Organization of the Study

The thesis has seven chapters. The first chapter is about introduction of the study. It contains background of the study, statement of the problem, significance of the study and scope of the study. The second chapter is intensive literature review from different sources on concept of maintenance in global and Africa level, maintenance triggers, strategies, performance indicators, maintenance management frameworks.

The third chapter is research methodology. In this chapter Data collection and presentation methods, data analysis tools, sampling, sampling techniques and methodology framework presented in detail.

The fourth chapter is company profile. Company vision, mission core value and organizational structure included. The fifth chapter is data collection, presentation and analysis. The primary data collected from the different sources through observation, interview and questionnaires properly integrated and presented in a descriptive manner as per the objective of the study. Data analyzed with the help of overall equipment efficiency analysis, cause and effect diagram and different statistical tools.

The sixth chapter will be developing of maintenance management system for the case company and its implementation procedure. The seventh chapter is conclusion and recommendation.

Chapter 2: Literature Review

2.1. Definition of terms

Maintenance is a function that must be performed under normally adverse circumstances and stress, and its main objective is to rapidly restore the equipment to its operational readiness state using available resources.

Maintenance is combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function (EN 13306, 2010).

Conceptual framework is a framework that explains either graphically or in narrative form of the main things to be studied; their key factors, constructions or variables and the presumed relationships among them (Parida et al., 2015).

Maintenance has traditionally been considered as a necessary evil, but it is in fact rather a center of profit than just unavoidable and unpredictable expense (Alsyouf, 2007).

However, according to Kumar and Parida maintenance is defined as the combination of all the technical and administrative actions, including supervision, intended to retain an item, or restore it to a state in which it can perform a required function. Maintenance management makes use of some tools and techniques to improve efficiency and minimize the impacts of unplanned stoppages looking for reducing costs (A. Parida and U. Kumar, 2006).

Maintenance must be an integral part of the production strategy for the overall success of an organization and its main objective is to rapidly restore the equipment to its operational readiness state using available resources (Zweekhorst, 1996)

It is becoming a major function that effects and is affected by many other functional areas such as production, quality, inventory, marketing and human resources. It is also getting to be considered as an essential part of the business supply chain at a global level. This increasing role of maintenance is reflected in its high cost, which is estimated to be around 30 per cent of the total running cost of modern manufacturing and construction businesses (Al-Turki, 2011).

Maintenance management is all activities of the management that determine the maintenance objectives, strategies and responsibilities, and implementation of them by such means as maintenance planning, maintenance control, and the improvement of maintenance activities and economics (EN 13306, 2010). Also Wireman defined maintenance as Asset Management, as the management of all assets owned by a company, based on maximizing the return on investment in the asset (Wireman, 2005).

Maintenance performance measurement is defined as the multidisciplinary process of measuring and justifying the value created by maintenance investment, and taking care of the organization's stockholders' requirements viewed strategically from the overall business perspective (Parida and Chattopadhyay, 2007)

A common occurrence when reviewing literature is the fact that authors use an array of terms and words to describe the same or similar concept. The study of maintenance management is no different with terms such as: maintenance models; maintenance methods; maintenance techniques; maintenance systems; maintenance types; maintenance philosophies; and maintenance strategies regularly used Maintenance management models throughout the literature to describe the same notion on maintenance (Parida et al., 2014, Parida et al, 2015 and Kym, 2015).

2.2. Maintenance concept globally

Due to the increasing technical advancements, the stimulus of productivity and quality is moving from man to machine. Productivity and quality may be increased only by implementing well-developed and organized maintenance system (Phogat and Gupta, 2017).

Maintenance is normally perceived to have a poorer rate of return than any other major budget item. Yet, most companies can reduce maintenance costs by at least one-third, and improve the level of productivity, by giving maintenance the management priority it requires. That priority must span all levels of an organization's management structure to develop an understanding at each level of the significance maintenance can have upon the success or failure of organization objectives (Ahuja and Khamba, 2007). Each year billions of dollars are spent on equipment maintenance around the world. Over the years, many new developments have taken place in this area (IMCP, 1975). Wireman, 1990, Jonsson, 1999 and McKone et al., 2001 as original cited by Naughton, 2012, maintenance was viewed with distain by management accountants and seen as a

drain on the bottom line, but with the introduction of the concept of value in maintenance, the true role of effective maintenance is slowly being recognized. This revolution is somewhat hindered by the fact that maintenance as a management strategy is somewhat underdeveloped when compared to other management disciplines such as operations management.

In 21st century new thinking and new strategies will be required to realize potential benefits and turn them into profitability. All in all, profitable operations will be the ones that have employed modern thinking to evolve an equipment management strategy that takes effective advantage of new information, technology, and methods. The economic downturn and the dynamic business environment drive companies to seek more efficient and effective maintenance. Thus, the increasing competition in the market creates a need to search new ways in which companies can differentiate themselves and gain more profit and better competitive position (Maletic et al., 2014).

Maintenance has two parts: an engineering and management part. The engineering part of maintenance is all about to improve maintenance operations, reduce the amount and frequency of maintenance, reduce the effect of complexity, reduce the maintenance skills required, reduce the amount of supply support, establish optimum frequency and extent of preventive maintenance to be carried out, improve and ensure maximum utilization of maintenance facilities, and improve the maintenance organization. On the other hand, the management part talks about all the activities of management that determine the maintenance objectives or priorities (defined as targets assigned and accepted by the management and maintenance department), strategies (defined as a management method in order to achieve maintenance objectives), and responsibilities and implement them by means such as maintenance planning, maintenance control and supervision, and several improving methods including economical aspects in the organization the function of providing policy guidance for maintenance activities, in addition to exercising technical and management control of maintenance programs (Adolfo, 2007).

Maintenance organization in a plant can be centralized or decentralized by considering company size, complexity, and product produced.

Past experience indicates that in large plants a combination of centralized and decentralized maintenance normally works best. The main reason is that the benefits of both the systems can be achieved with essentially a low number of drawbacks. Nonetheless, no one particular type of maintenance organization is useful for all types of enterprises (Dhillon, 2001). Whereas Haroun

and Duffuaa (2009) and Wireman (2005), classify maintenance organizational structure is three types, centralized, decentralized and matrix or Hybrid structure.

Establish reasonably clear division of authority with minimal overlap, optimize number of persons reporting to an individual, fit the organization to the personalities involved, and keep vertical lines of authority and responsibility as short as possible useful guidelines planning a maintenance organization. The maintenance team is an important factor that demands strategies to improve competence level. Thus, it is necessary to manage activities and resources allowing the maintenance area to accomplish its function (Marcelo et al., 2014).

Literatures show that maintenance management is very important for the performance of the company (Pintelon, 2002, Enofe and Aimienrovbiy, 2010, Pintelon 2002, Parida et al., 2015).

Table 2.1: Emerging trends in maintenance (Pintelon, 2002 and Garg, 2006)

| Attribute | Earlier | Emerging |
|---|--|---|
| Manpower | Simple | Mechanization-Automation-Globalizations(crossing boundaries) |
| Attitude towards maintenance | Necessary evil | Technical matter–profit contributor–partnership |
| Maintenance strategy | CM-PM-RCM-TPM | Integration of various approaches, e.g. ECM, SMM, etc. |
| Maintenance optimization models(quantitative) | Mathematical discipline with limited applications | Application oriented, integration with qualitative approaches |
| Maintenance outsourcing | Not existed | Part of vertical contracting |
| Maintenance scheduling | Models in isolation | Integration with MMIS |
| Performance indicators | Reference numbers, surveys, indicators, models –Hibi and Luck | Maintenance management tool(MMT)model |
| Performance measurement approaches | Value based approach, systems audit approach, data envelopment analysis(DEA) | Balance score card(BSC)approach, Quality function deployment(QFD) |
| PMS integration within formation system | Poor | Developing |
| Data collection in measurement of OEE | Not sufficiently treated | Designing of data collection system |
| Evolution of MMIS | Main frame applications and mostly administration oriented | Evolution in middle ware software(e.g. communication between corporate and plant floor), workgroup computing, |

| | | |
|--------------------------|--------------------------|--|
| | | integrated system technology, inter-enterprise technology. |
| Spare parts management | Inventory administration | Graphical user interface(GUI)– maintenance management information systems(MMIS). |
| New maintenance policies | Techniques in isolation | Maintenance strategy in MRP system, Joint implementation of TQM, JIT and TPM, neural management maintenance, customized maintenance concept framework, object-oriented maintenance management model and its integration to ERP, knowledge of maintenance engineers utilization, correlation between change over performance and maintenance tasks. |

A total of 9 maintenance management frameworks and related tools and techniques are reviewed for this paper and the details are found on maintenance management section.

2.3. Maintenance in Africa

Only few literatures can be discovered in Africa level this shows that more emphasis needs to be given on maintenance area. Revealed literatures are more on evaluation of maintenance management system, improving quality and productivity through maintenance management system. A total of four thesis and four articles reviewed.

Table 2.2: literatures of maintenance concept in Africa

| No. | Title | Type | Year | Area |
|-----|---|--------|------|------------------------|
| 1 | Productivity improvement in Ethiopian leather industry through efficient maintenance management | Thesis | 2007 | Maintenance management |
| 2. | A study on the impact of maintenance management systems on maintenance | Thesis | 2012 | Maintenance management |

| | | | | |
|----|--|---------|------|------------------------|
| | condition of built facilities (case study of public universities in Kenya) | | | |
| 3. | Quality and productivity improvement in Ethiopian foot ware industries through maintenance management system | Thesis | 2013 | Maintenance management |
| 4. | Maintenance management practices and operational Performance in electricity producing stations in Kenya | Thesis | 2014 | Maintenance management |
| 5. | Maintenance approaches for different production methods | Article | 2013 | Maintenance approaches |
| 6. | Evaluation of maintenance in manufacturing industries in Akure metropolitan of Nigeria. | Article | 2012 | Maintenance management |
| 7. | Total productive maintenance: a case study | Article | 2012 | Maintenance approach |
| 8. | Development and implementation of preventive maintenance practices in Nigerian industries | Article | 2006 | Maintenance approach |

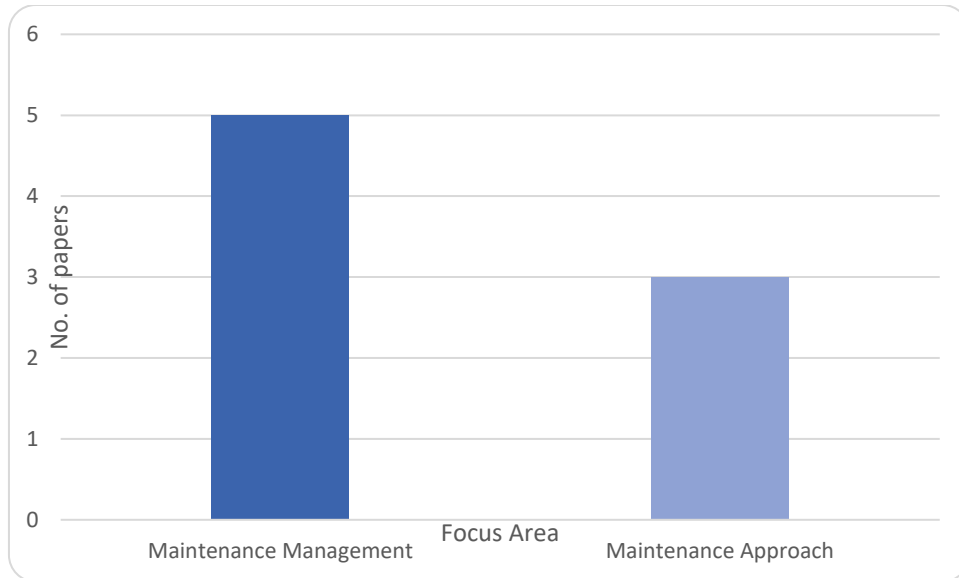


Figure 2.1: Reviewed papers at Africa level

Maintenance practice in Ethiopia is still in an infant stage. Status of maintenance in Ethiopian industries is unknown and also there is no organized body that works on maintenance

2.4. Basic Maintenance philosophies

2.4.1. Maintenance triggers

When maintenance triggers occur, it indicates that maintenance must be performed at an operational level. Maintenance triggers are used to alert a technician that maintenance is required. When maintenance triggers are received the operational requirements for the maintenance can be planned, acted upon, and recorded using a CMMS.

There are five main maintenance triggers: breakdown, time-based, event-based, usage-based, and condition-based (Pintelon, 2002, Muchiri, 2011, Sinha, 2015, Shin and Jun, 2015, Phogat and Gupta, 2017). The details are as below:

- **Breakdown trigger:** Breakdown maintenance triggers are initiated when a piece of equipment breaks down into an unusable state. With these maintenance triggers, maintenance is necessary in order to return the equipment to operation. A breakdown trigger is the only maintenance trigger that is used when a maintenance strategy has not been designed at a tactical or strategic level.

If the maintenance plan for the equipment has been designated as a run-to-failure strategy, then a breakdown trigger is the only trigger that is used for maintenance of that machine. In this case, the maintenance, while unscheduled, remains planned maintenance.

When the equipment has a preventative maintenance strategy, a breakdown trigger initiates maintenance that is both unplanned and unscheduled.

- **Usage Trigger:** A common example of a usage trigger for maintenance is the schedule suggested by car manufacturers. For example, a car manufacturer may suggest maintenance every 10,000 km. This type of maintenance is triggered through recorded meter data. Other examples include usage based on hours of use and number of production cycles.
- **Condition Trigger:** A condition-based trigger for maintenance occurs after the condition of the equipment has been assessed and consequently determined to be unsatisfactory for continued use without maintenance being planned. Various techniques can be used to assess the condition of a machine, ranging from inexpensive methods such as visual inspection through to more technically demanding techniques such as vibration monitoring and thermographic analysis.

Condition is the most complex trigger for maintenance. This is because data about condition must be obtained and interpreted. Often the equipment required to perform condition monitoring requires specialized training and experience to operate effectively. After the data is analyzed, it may indicate that maintenance is required.

- **Time Trigger:** Time is used frequently as a trigger for maintenance activities. With a time trigger, maintenance is triggered whenever the calendar rolls over to a pre-specified date. Because the calendar is so easily predicted, time is the least complex trigger to schedule planned maintenance.

Time can be used as a trigger in many ways. It can be used to trigger maintenance on regular intervals, say every 6 weeks. It can also be used to trigger maintenance based on the seasons, such as “change air conditioner filters before summer”.

- **Event Trigger:** When maintenance needs to occur due to an external event, an event trigger may be used. For example, in a building, a series of maintenance tasks may need to be triggered

if flooding occurred in the basement. These tasks could include electrical checks, cleaning and boiler checks.

Table 2.3: classification of maintenance type based on maintenance triggers

| S. No. | Maintenance trigger | Maintenance type |
|--------|---------------------|--|
| 1. | Breakdown | Run to failure, corrective and preventive |
| 2. | Usage | Preventive, Condition based and Predictive |
| 3. | Condition | Condition based and Predictive |
| 4. | Time | Preventive, Condition based and Predictive |
| 5. | Event | Preventive Condition based and Predictive |

2.4.2. Maintenance strategies

There are many different approaches that can mix and match, depending on the type of assets, industry, and the size and experience of the maintenance team.

- **Run to failure (breakdown maintenance)**

Its basic philosophy is allowing machinery to run to failure and repair or replace damaged equipment when obvious problems occur (Mungani and Visser, 2013).

Equipment designated as run-to-failure are fixed in the event of a breakdown (by repair, restoration or parts replacement) until it is more feasible to simply order a replacement equipment. this strategy is an acceptable strategy for equipment that is of minimal importance to operations (rarely used or duplicates the function of some other equipment) or has low cost(Wireman, 2005).

- **Preventive (scheduled) maintenance (PM)**

Dhillon (2001), mentioned the characteristics of a company that need to implement preventive maintenance:

- Low equipment uses due to failures
- Large volume of scrap and rejects due to unreliable equipment

- Rise in equipment repair costs due to negligence in areas such as regular lubrication, inspection, and replacement of worn items/components
- High idle operator times due to equipment failures
- Reduction in capital equipment expected productive life due to unsatisfactory maintenance

PM may also be described as the care and servicing by individuals involved with maintenance to keep equipment/facilities in satisfactory operational state by providing for systematic inspection, detection, and correction of incipient failures either prior to their occurrence or prior to their development into major failure (Marcelo et al., 2014).

Some of the main objectives of PM are to:

- Enhance capital equipment productive life,
- Reduce critical equipment breakdowns,
- Allow better planning and scheduling of needed maintenance work,
- Minimize production losses due to equipment failures, and promote health and safety of maintenance personnel.

On preventive maintenance strategy equipment's needs to be inspected periodically, lubricate, cleaned, calibrated, tested all electrical & mechanical parts are fully functional and replaced any damaged parts so as to run the equipment in a good condition.

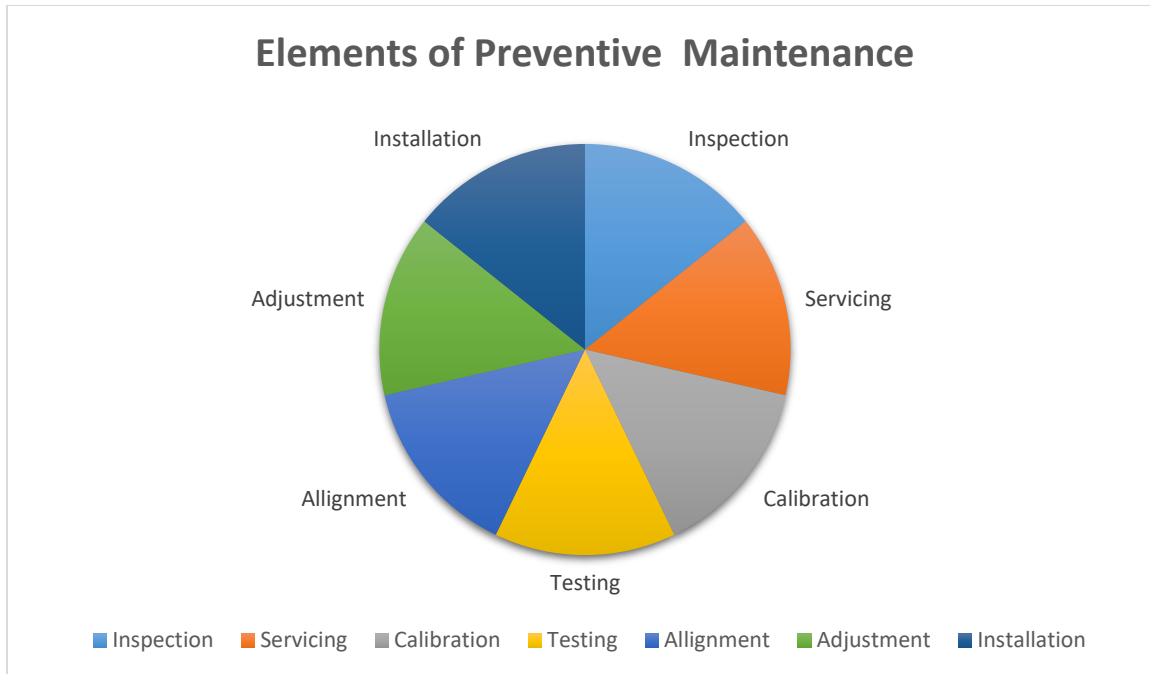


Figure. 2.2: Elements of Preventive Maintenance

✓ **Predictive maintenance (PdM):**

Predictive maintenance is often referred to as condition based maintenance (CBM). In this strategy, maintenance is initiated in response to a specific equipment condition or performance deterioration. (Alyouf, 2007 and Phogat and Gupta, 2017).

Predictive maintenance is the monitoring of equipment operating conditions to detect any signs of wear that is leading to a failure of a component. The goal of the predictive maintenance program is to track the component wear with a methodology that insures that any impending failure is detected. Once detected, the component wear is tracked more closely. This methodology includes different monitoring and diagnostic techniques such as; vibration monitoring, thermography, tribology, process parameters, visual inspection and other nondestructive testing techniques. Ineffective planning and improper repairs restrict the benefits of predictive maintenance. (Dhillon, 2002 and Wireman, 2005)

Predictive maintenance program can minimize unscheduled breakdowns of equipment's by providing data's' required to schedule both preventive and corrective maintenance tasks on as needed base. Predictive maintenance has wide applications in automotive, aviation, manufacturing, defense, and other industries (Ashok et al., 2012).

✓ **Reliability-centered maintenance (RCM):**

Reliability centered maintenance (RCM) is a corporate-level maintenance strategy that is implemented to optimize the maintenance program of a company or facility. The final result of an RCM program is the implementation of a specific maintenance strategy on each of the assets of the facility. The formulation of the maintenance strategies is by selecting the right mix of corrective maintenance, scheduled-based (or preventative) maintenance, and CBM to fully support the reliability of the system in any given operational environment (Ashok et al., 2012).

Reliability centered maintenance program principles are.

- The primary objective is to preserve system function.
- Identify failure modes that can affect the system function.
- Prioritize the failure modes.
- Select applicable and effective tasks to control the failure modes

An effective reliability centered maintenance implementation examines the facility as a series of functional systems, each of which has inputs and outputs contributing to the success of the facility. Literature claims that if RCM approaches will be applied correctly, it reduces the amount of routine maintenance work by 40-70 percent (Probert et al., 2006). It is the reliability, rather than the functionality, of these systems that are considered. The seven questions that need to be asked for each asset are:

- a. What are the functions and desired performance standards of each asset?
- b. How can each asset fail to fulfill its functions?
- c. What are the failure modes for each functional failure?
- d. What causes each of the failure modes?
- e. What are the consequences of each failure?
- f. What can and/or should be done to predict or prevent each failure?
- g. What should be done if a suitable proactive task cannot be determined? (Keith Mobley et al., 2008)

Reliability-centered maintenance identifies the functions of the company that are most critical and then seeks to optimize their maintenance strategies to minimize system failures to ultimately increase equipment reliability and availability. The most critical assets are those that are likely to

fail often or have large consequences of failure. With this maintenance strategy, possible failure modes and their consequences are identified; all while the function of the equipment is considered. Cost-effective maintenance techniques that minimize the possibility of failure can then be determined. The most effective techniques are then adopted to improve the reliability of the facility as a whole.

The 7 steps for implementing reliability centered maintenance

There are several different methods for implementing reliability centered maintenance that are recommended, summarized in the following 7 steps.

Step 1: Selection of equipment for RCM analysis

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

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

Step 4: Identify the root causes of the failure modes

Step 5: Assess the effects of failure

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

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

In short, one of the biggest disadvantages of RCM II is its complexity and, as a consequence, its price. Reliability, rather than maintainability and availability is the main object. Such an approach is justifiable in aircraft/airline industries and in high tech/high-risk industries, but is often too expensive in general industries, where maintenance is rather an economic than a reliability problem (Pintelon, 2002).

✓ **Risk-based maintenance**

Risk-based maintenance (RBM) prioritizes maintenance resources toward assets that carry the most risk if they were to fail. It is a methodology for determining the most economical use of maintenance resources. This is done so that the maintenance effort across a facility is optimized to minimize any risk of a failure (Sakai, 2010 and Khan and Haddara, 2003).

A risk-based maintenance strategy is based on two main phases:

1. Risk assessment.
2. Maintenance planning based on the risk

The maintenance type and frequency are prioritized based on the risk of failure. Assets that have a greater risk and consequence of failure are maintained and monitored more frequently. Assets that carry a lower risk are subjected to less stringent maintenance programs. Implementing a risk-based maintenance process means that the total risk of failure is minimized across the facility in the most economical way.

The monitoring and maintenance programs for high risk assets are typically condition-based maintenance programs. Risk-based maintenance is a suitable strategy for any maintenance plan. As a methodology, it provides a systematic approach to determine the most appropriate asset maintenance plans. Upon implementation of these maintenance plans, the risk of asset failure will be low (Arunraj and Maiti, 2007).

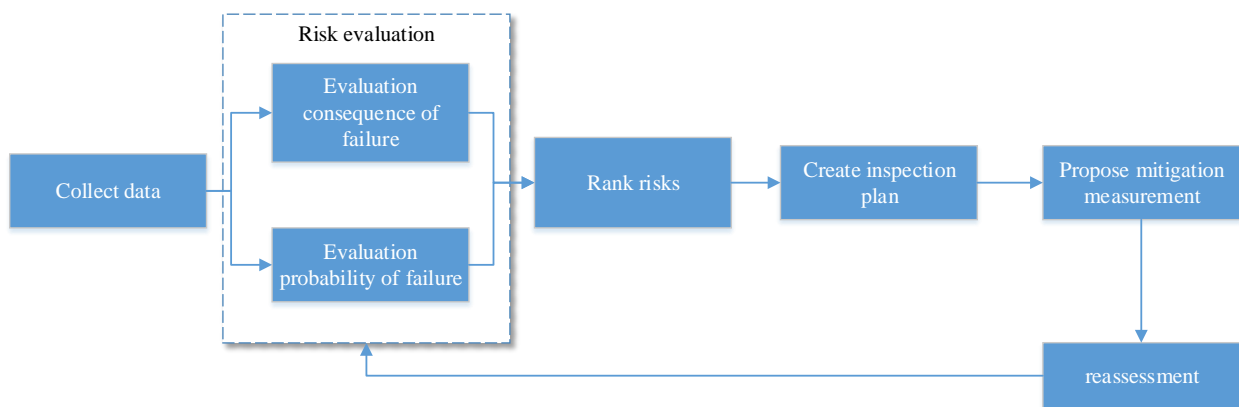


Figure 2.3: Risk based maintenance framework

The risk-based maintenance framework is applied to each system in a facility. A system, for example, may be a high-pressure vessel. That system will have neighboring systems that pass fluid to and from the vessel. The likely failure modes of the system are first determined. Then, a typical risk-based maintenance framework is applied to each risk.

For each identified risk, data needs to be collected. This includes information about the risk, its general consequences and the general methods used to mitigate and predict the risk.

At the risk evaluation stage, both the probability of the risk and the consequence of the risk are quantified in the context of the facility under consideration. With the risk evaluation complete, the probability and consequence are combined to determine the total risk. This total risk is ranked against pre-determined levels of risk. As a result, the risk is either acceptable or unacceptable.

If the risk is unacceptable, a plan to inspect the system using a condition monitoring approach is determined. Or, if it is more cost appropriate, and technically feasible a preventative maintenance program might be selected.

At this stage the proposal for mitigating the risk, using the condition monitoring and maintenance approach, is prepared.

Finally, the proposal is evaluated against other factors – such as legal and regulatory requirements. If the proposal's needs are not met, then the process starts again. Otherwise, the maintenance proposal is put into place.

There is no one standard method for assessing risk. Qualitative, semi-quantitative and quantitative approaches are used to determine the possible risks that exist. To estimate the likelihood of these risks, the methods that are used include deterministic, and probabilistic approaches. 62 different approaches to assessing risk are described in Tixier, (2002). The most appropriate approach will depend on the data that is available to evaluate each risk. Assessing the risk of failure is one of the most important aspects of risk based maintenance. The more accurately this is done, the better the risk based maintenance outcomes will be (Sakai, 2010).

✓ **Total productive maintenance**

Total Productive Maintenance (TPM) is an approach to maintenance developed in Japan that brings the tools of total quality management (TQM) to maintenance. The only change is that

instead of companies focusing on their products, their focus shifts to their assets. All of the tools and techniques used to implement, sustain, and improve the total quality effort can be utilized in TPM (Wireman, 2005). The aim of TPM is to reduce six categories of equipment losses to improve overall equipment effectiveness (OEE). The six major causes of equipment losses, according to Nakajima (1988) are:

1. Failure;
2. Set-up and adjustments;
3. Idling and minor stoppage;
4. Reduced speed;
5. Process defects; and
6. Reduced yield.

TPM empowers operators and uses multi-skilled crafts to minimize response time and perform productive maintenance. The implementation is expected to assist in improving maintenance effectiveness and control (Ben-Daya et al., 2009).

Tsuchiya (1992), original cited by McKone sweet and Schroeder (1999), TPM is designed to maximize equipment effectiveness (improving overall efficiency) by establishing a comprehensive productive-maintenance system covering the entire life of the equipment, spanning all equipment-related fields (planning, use, maintenance, etc.) and, with the participation of all employees from top management down to shop-floor workers, to promote productive maintenance through motivation management or voluntary small-group activities.

TPM is an innovative approach, which holds the potential for enhancing the efficiency and effectiveness of production equipment by taking advantages of abilities and skills of all individuals in the organization. TPM focuses on maximizing the Overall Equipment Efficiency (OEE) with involvement of each and everyone in the organization. It will not only establish a complete maintenance system, but also aims to improve the maintenance skills and knowledge among the shop floor operators. Now, TPM and its implications received prestigious worldwide recognition in achieving the ultimate Zero Defects and Zero Breakdown targets.

Fewer breakdowns, safer workplace and better overall performance are few advantages of TPM. Under the TPM philosophy, everyone from top-level management to equipment operators should participate in maintenance.

- ✓ Top management & reliability engineers
- ✓ Operators
- ✓ Maintenance managers and technicians

TPM is built on a 5S foundation, with eight supporting pillars. The beginning of a TPM program will focus on establishing the 5S foundation and developing an autonomous maintenance plan. This will free up the maintenance staff to begin larger projects and perform more and more planned maintenance.

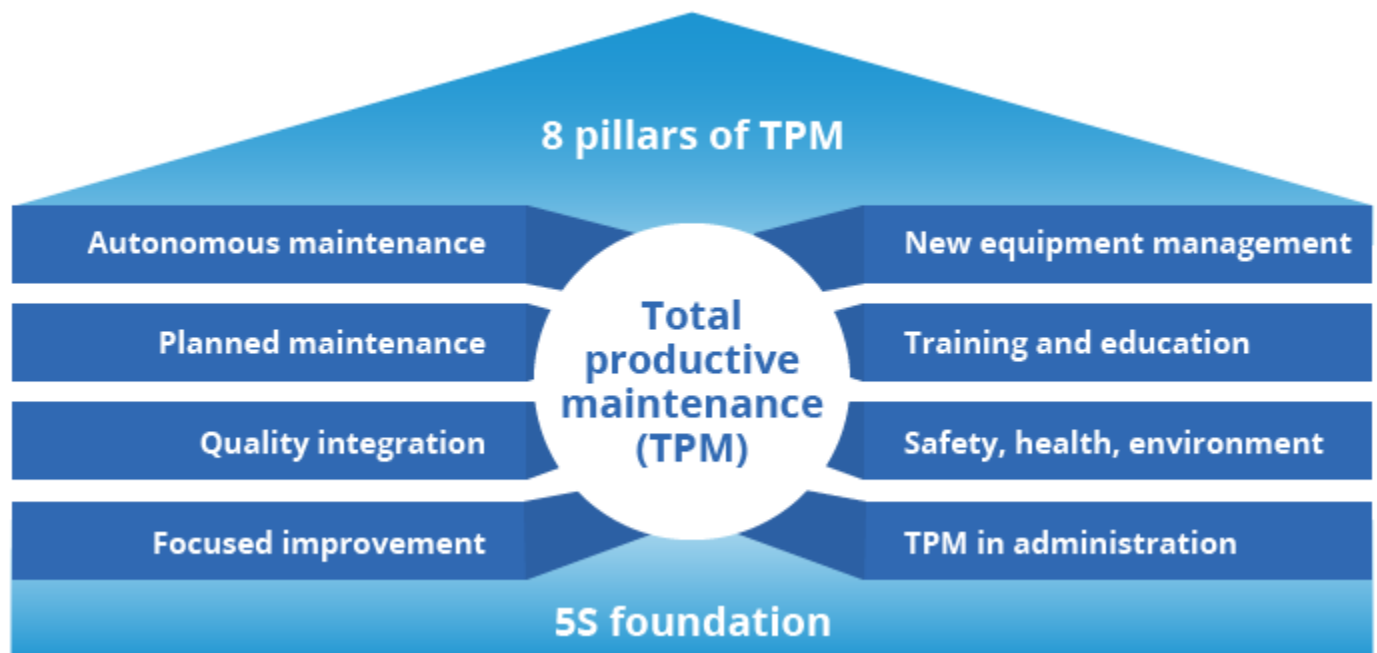


Figure 2.4: Foundation and pillars of TPM

5 S

Sort: Determine which items are used frequently and those that are not. The ones used frequently should be kept close-to-hand, others should be stored further away.

Systemize: Each item should have one place to be stored, and only one place to be stored.

Shine: The workplace needs to be clean, without it problems will be more difficult to identify, and maintenance will be more difficult to perform

Standardize: The workplace should be standardized and labeled.

Sustain: Efforts should be made to continually perform each of the other steps at all times.

Once the foundation is laid, then the system will move on to establishing the eight pillars of TPM. If this 5S is not taken up seriously, then it leads to 5D (delays, defects, dissatisfied customers, declining profits, and demoralized employees).

TPM is a maintenance philosophy, but there are tangible KPIs that accompany it. One of the most important measurements of total productive maintenance is overall equipment effectiveness (OEE), which measures availability, performance efficiency, and quality. As such, equipment stopping, equipment working at less than peak capacity, and equipment producing poor quality products are all penalized when OEE is determined.

TPM does not provide clear rules to decide which basic maintenance policy will be used (Failure Based Maintenance, Design-Out Maintenance, Detective Based Maintenance, Condition Based Maintenance or Use Based Maintenance). In fact, TPM is more and more translated as Total Productive Manufacturing or Total Productive Management. In this light, TPM is more like a management strategy (Pintelon, 2002). In contrast with some other maintenance concepts, TPM contains nothing that is wrong or detrimental to company economics. This is another reason why TPM is incomplete as a maintenance concept

✓ **Value driven maintenance**

Haarman and Delahay (2006), original cited by Senstrom et al., (2013), Value-driven maintenance (VDM) is not a maintenance type, but rather a philosophy developed by the founders of Mainnovation, Mark Haarman and Guy Delahay, for optimizing the value derived from maintenance at any particular point in time. The decision to perform maintenance at any time is based on cost/benefit analysis. It requires a delicate balancing between the value that improved reliability can bring and the cost of maintenance. Value driven maintenance (VDM) is a methodology developed on four value drivers in maintenance, like; asset utilization, resource allocation, cost control and health, safety and environment (HSE).

Increasing availability means more units can be produced with the same equipment, generating more income while fixed costs remain unchanged. Resources are spare parts, labor, contractor labor, and knowledge. Whereas the consumption of those resources is covered under cost control; the resource allocation driver focuses on smarter management of those resources. Good SHE policy it can have a significant negative affect on future cash flows if done incorrectly. Maintenance related incidents that injure personnel, damage equipment or have a negative effect on the environment will increase expenditure through litigation or imposed government penalties. Salaries, contractor fees, parts, emergency shipments and specialist tools consume maintenance budgets. Reducing reactive maintenance and thus limiting the need for external contractors, emergency parts and technicians overtime can increase value by eliminating expenditure.

$$PVPM = \sum \frac{(FSHE,t)*[(CFAU,t)+(CFCC,t)+(CFRA,t)+(CFSHE,t)]}{(1+r)*t}$$

Where:

PVPM: present value potential of maintenance

FSHE,t: She factor in a year t (% compliance with SHE regulations)

CFAU,t: future cash flow in year t from asset utilization

CFCC,t: future cash flow in year t from the cost control

CFRA,t: future cash flow in year t from resource allocation

CFSHE,t: future cash flow in year t from She

r: discount rate

✓ **Total Quality Maintenance (TQMain)**

This model was developed by Dr Basim Al-Najjar, as part of his PhD dissertation, It is soundly based on the Deming cycle (plan-do-check-act plan, etc.), which is the foundation of TQM, and can be used for the improvement of any technical or managerial system. (Sherwin, 2000).

TQM is a means to maintain and improve continuously the technical and economic effectiveness of the production process and its elements, i.e. it is not just a tool to serve or repair failed machines rather than a means to maintain the quality of all the elements involved in the production process. It is a means for monitoring and controlling deviations in a process, working conditions, product quality and production cost, and for detecting damage causes and their developing mechanisms and potential failures in order to interfere (when it is possible) to “stop” or reduce machine deterioration rate before the production process and product characteristics are intolerably affected and to perform the required action to restore the machine/process or a particular part of it to as good as new. All these should be performed at a continuously reducing cost per unit of good quality product (Al-Najjar, 2008).

Total quality maintenance is known as total predictive maintenance. Total predictive maintenance (TPM) originated in Japan in 1971 as a method for improved machine availability through better utilization of maintenance and production resources (Sharma and Khatri, 2015).

TPM and TQM have a common and continuous goal of waste reduction. Some of the common themes of the two value systems include continuous improvement, employee empowerment, process focus, information gathering and analysis, and top management commitment. This implied commitment takes into account the interests of customers, employees, shareholders, the competitor and society at large. The two approaches emphasize effective management of primary factors such as top management leadership, process management, employee training and empowerment. The results are achieved through secondary benefits such as lower costs, improved reputation and market share, and increased employee motivation and satisfaction. The objectives of the two philosophies do not explicitly state improvement in profitability, nevertheless, with objective execution they will inevitably follow (Brah and Chong, 2004).

One of the major differences between TPM and TQM lies in customer focus. While TQM explicitly emphasizes customer focus, TPM implicitly considers the customer dimension through waste reduction, productivity improvement, timeliness and planning of activities, gathering and analyses of data, and improvement of quality. In addition, while there are many studies linking TQM programs and organizational performance, its close ally TPM has not received widespread attention

Features, Applicability and Benefits of TQMain

The features characterizing TQMain and distinguishing it from other maintenance techniques, such as preventive (PM), condition-based (CBM), reliability-centered (RCM) and total productive maintenance (TPM) can be summarized in the following:

- ✓ It covers a wider range of a production process compared with the traditional maintenance concept, which deals with just machinery.
- ✓ It is based on a new CBM concept. It is planned and performed based on the needs arise due to the deviations in the quality of the elements involved in the production process.
- ✓ It handles production and maintenance technical and financial problems by integrating tools and methods belong to both deterministic and probabilistic approaches.
- ✓ It advocates the use of a common database that should be updated by real-time measurements of the essential information parameters, for real-time monitoring and assessment of the machine condition and production process technical and economic effectiveness, product quality and working environment. Thus, within TQMain, it is possible to select and improve the most informative CM system and the most cost-effective maintenance policy effectively.
- ✓ Consequently, it provides a holistic view of the state of the production process (including all the elements involved), maintenance technical & financial impact on company business
- ✓ It is based on making intensive use of the real-time data acquisition and analysis to detect at an early stage the causes behind quality and cost factors deviations and machinery malfunctions, and following damage/defect development to prolong the component mean effective life and to improve company's profitability and competitiveness.
- ✓ It provides tools and methods for proactive-predictive maintenance, i.e. to detect and eliminate the cause behind damage initiation. If it is not possible due to the technological limitation, detect the deviation at an early stage and predict its development to reduce (or eliminate) the risk of failure.
- ✓ It emphasis on the systematic maintenance work combining technical, organizational and economic knowledge and experience, where all the theories, tools and methods required are, more or less, developed and verified. This systematic maintenance work starts by detecting the deviation/damage at an early stage, identifying damage initiation causes and

developing mechanisms and predict the situation in the close future technically and financially.

- ✓ It provides the basis for cost-effective continuous improvement of the whole production process and in particular vibration/condition-based maintenance policy after each renewal through confronting database history, including vibration measurements, with the replaced components, i.e. continuous cyclic improvement.

2.5. Maintenance management

A good maintenance management system makes equipment and facilities available. Availability means the production team can demand and receive any item such as light, power, air, gas, heating, cooling, or machine tools when it is needed. If the required equipment or service is down, or if the machine stops short of completing a job, time and money are wasted. A good maintenance management system helps to accomplish minimal downtime (Kishan, 2006).

Literature on maintenance management has so far been very limited (Goyal and Maheshwari, 2012). maintenance concepts vary from organization to organization. There is no one-fits-all solution and the literature published around generic commercial frameworks (Pintelon, 2002, Naughton 2012,). Basic steps of management stated by Kishan (2006), is request, approval, plan, schedule, performing work, recording data accounting for costs, developing management information, updating equipment history and providing management control reports.

Elements of effective maintenance management includes

- i. Maintenance Policy:
- ii. Material Control
- iii. Work Order System
- iv. Equipment Records
- v. Preventive and Corrective Maintenance
- vi. Job Planning and Scheduling
- vii. Backlog Control and Priority System
- viii. Performance Measurement

2.5.1. Maintenance management framework

In this section former developed frameworks are reviewed. Maintenance must be considered holistically so as to develop an appropriate maintenance concept.

1. Maintenance Framework 1

On their paper, Vanneste and Van Wassenhove (1995) present a brief review of developments in maintenance theory and practice, and in information technology and decision support models. The model is an integrated approach that combines elements from these domains into a powerful tool for dealing with maintenance problems. They also show how this framework can be used to set up a continuous improvement program for maintenance management and apply the concepts to an industrial case.

The approach has eight phases by improving Deming cycle.

Phase 1 obtain a clear picture of a current factory performance: at this stage list of questions developed in order to have a clear picture of the organization.

Phase 2. Analyze quality and down time problems. At this phase location of the majority quality and downtime problems, relative importance, frequency of occurrences, causes and consequences identified by using histogram, pareto analysis, quality control charts, cause and effect diagrams, FMEA methods.

Phase 3. Analyze the effectiveness of alternative solutions to major problems. Different solutions generated and their hidden and tangible costs identified. They mentioned that both costs as well as benefits of a solution, especially in the hidden part are uncertain and difficult to estimate an exact value. Therefore, it is necessary to include scenario analysis. By comparing one solution cost benefit analysis with another solution, it became easy to prioritizes the proposed solutions. This phase has 4 steps:

1. Obtain a list of alternative solutions to each (major) problem.
2. Estimate the cost and benefits of each solution.
3. Make a prioritized list.
4. Select one or more solution

Phase 4. Analyze the efficiency of maintenance procedures. To identify how much preventive maintenance be to performed, how many spare parts to be kept in stock decision models used. The input for the models such as cost, lifetime distribution is obtained from effectiveness analysis, additional data analysis and experts opinion. At this phase 3 models selected, maintenance and replacement model (it is a maintenance field), spare part provisioning model (it is under Inventory management) and scheduling model (it is under production scheduling). Three models under maintenance and replacement model selected, these are Deterministic age replacement model, Probabilistic age replacement model and group replacement model. A common factor in these models is that the unit deteriorates as it gets older. Deterministic age replacement model is used to find optimal age of replacement in addition it is for a single unit system. The other two models used to find the optimal preventive age limit in addition to this it is used for a group of identical components'.

Phase 5. Plan action. Planning of actions and information process takes place to keep the track of the result. After defining performance measures and organizing the data gathering process target will be set.

Phase 6. Implement actions and gather data. Planned actions on phase five will be implemented and data's' will be collected.

Phase 7. Monitor actions and process data. And the last phase will be adapting actions or information procedures in case of undesired evaluation. The performance indicators (P.I.'s) provide a tool to measure certain quantities and to check whether and to what extent targets are met.

On the integrated approach efficiency analysis is preceded by effectiveness analysis. To study the maintenance efficiency optimal replacement frequency analysis used.

In order to initiate, monitoring and measuring continual improvement efforts maintenance Management Information System (MMIS) developed. This MMIS is user friendly that have 3 main components' performance indicators, data's and models.

The framework implemented on selected company in three steps. The first step is getting a picture of the quality and downtime problems, the next step is prioritizing actions (effectiveness), and the last step is improving the efficiency of maintenance procedures.

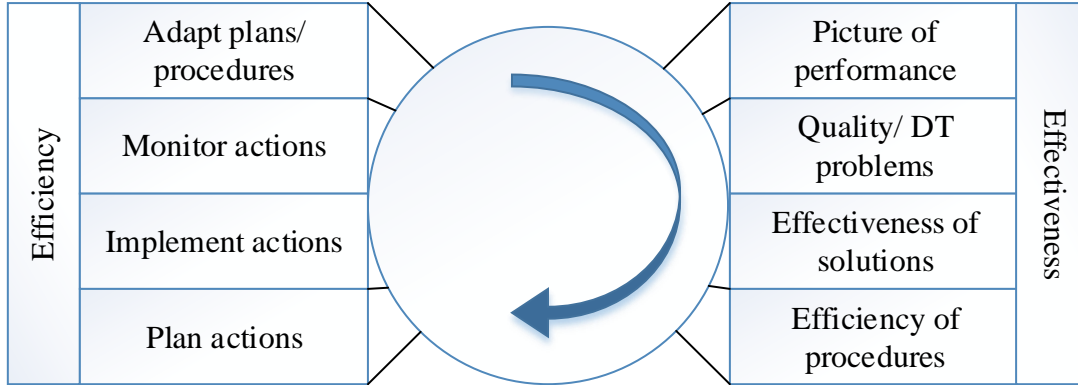


Figure 2.5: framework 1 (Vanesste and van Wassenhove 1995)

2. Framework 2

This framework offers a guideline to develop a customized maintenance concept. The paper emphasized that Maintenance concept should be unique for each company due to two reasons. One is the relevant factors are different from company to company and the other reason is high speed technological innovations. Due to this a flexible maintenance concept that allows feedback and improvement needs to developed. nowadays great emphasis is put on the availability, reliability and safety of production.

Computerized information used for information source in addition to that workers' experience and know-how (knowledge) considered. This is due to before the introduction of maintenance management information system information was kept on paper or in the head of the people. Different projects exercised before the developed model.

The first project was on automobile manufacturer. The goal was to develop an effective and efficient maintenance concept and to set up general framework to apply the concept other similar complex equipment in the future. Customized reliability centered maintenance II. Selected.

The second project was conducted on brewery. The main objective was to improve the yield. To understand the nature and causes of each type of loss historical data analyzed and total productive maintenance selected so as to improve the yield.

The third project was in process industry. For this project customized maintenance concept based on reliability centered maintenance II principles implemented. However, the result was far from the optimal.

From the other projects of life cycle cost studies in chemical process industry and pharmaceutical industry, a lesson learned that the used of standard concepts from literature is not an answer in most of the cases.

The framework was developed for a large process industry with the goal of developing total company maintenance for all different plants and all different installations. The proposed framework has six steps.

Step 1. Identification of objectives and resources: the first objective of maintenance is to secure reliability and availability, to reduce cost, protect their commercial margins, to meet the severe laws of safety and environment and to enhance productivity. In addition to the objectives requirements to meet the objective such as material, money, people and know-how needs to be identified.

Step 2. Identification of most important system: Depending on the objectives and the situation, weight factors can be used to underline the relative importance of each objective concerning bottlenecks, loss of production, etc. In most of the cases quite a few criteria have to be considered. Multi-criteria decision making (MCDM) techniques was very helpful for this step. Also, the process layout will influence the selection of a system as most important or not.

Step 3. Criticality analysis: here the most critical component with in the selected most important system identified. A simplified FMECA used in table form, economic and technical aspects and knowledge in human's head considered. The reason for this approach is that technical systems deal with layout, flow and equipment. Their performances visualized in terms of breakdowns, set-up losses, minor stoppages and quality defects. The intent of FMECA analysis is to identify components, which failure consequences could have an impact or jeopardize the systems performance (unplanned production stops), and/or cause dangerous situations for the personnel or the environment within the selected most important system. Most problems are due to disruptions between production and the different maintenance specialists and could be eliminated by increased collaboration between the different teams and by gathering all available tacit and explicit

knowledge. The advantage of this method is that it is fast and easy to use, while subjectivity is limited through the predefined borders.

Step 4. Maintenance policy decision steps: decision tree with the consideration of technical and economical aspect followed.

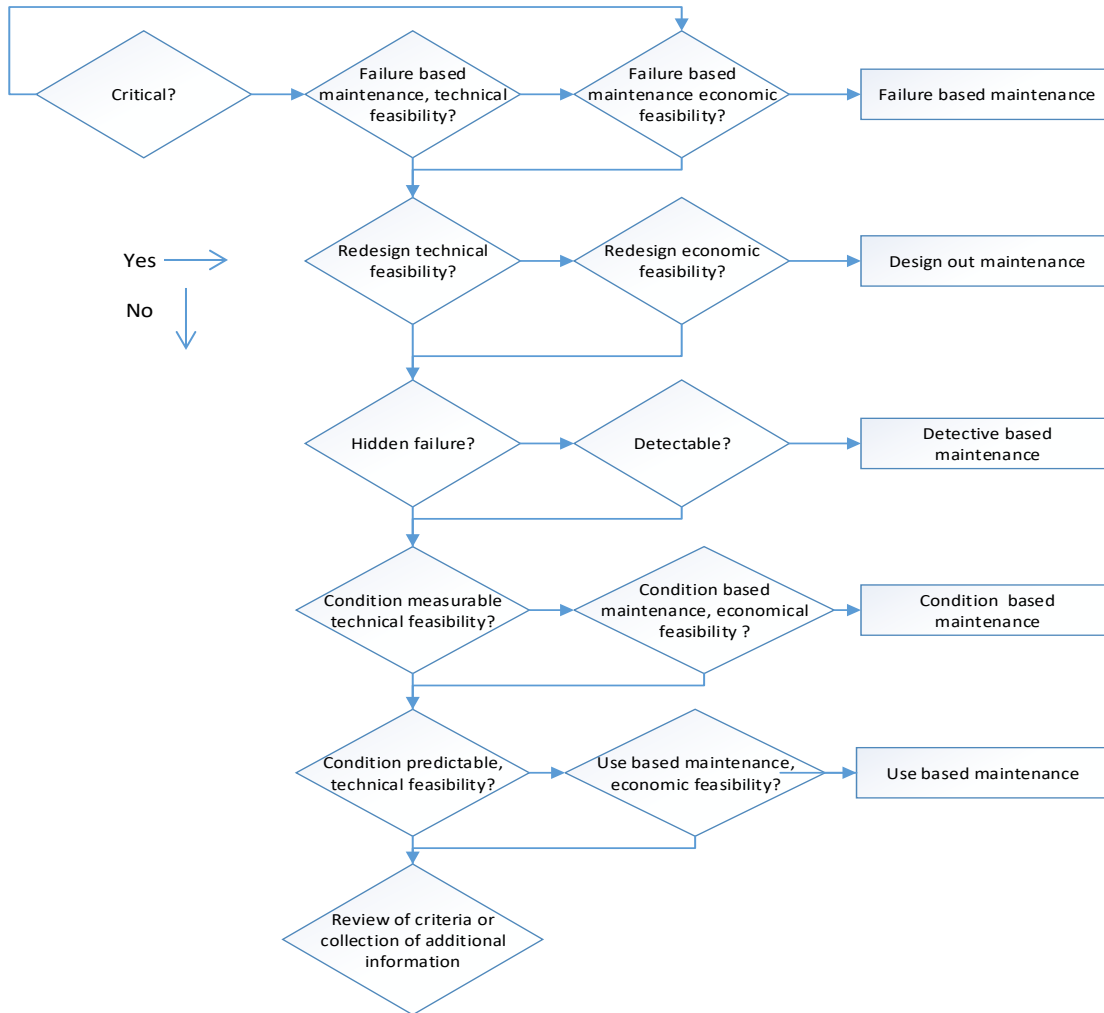


Figure 2.6: Maintenance policy decision tree (Waeyenbergh and Pintelon, 2002)

Step 5. Optimization of preventive maintenance policy: after the maintenance policy selected its parameters such as PM frequency should be optimized. In maintenance there are basic strategies block based and age based. Block based/ time-based strategy is an extension of block based. Both policies are based on renewal theory and the difference between the basic model and the extended one lies in the duration of the maintenance interventions (zero and finite respectively).

Step 6. Performance measurement and continuous improvement: two reasons stated for limited maintenance performance measurement. The first is maintenance performance reporting is difficult and the other reason is maintenance is closely related to other activities. Most of maintenance performance indicators are ratios measuring effectiveness, efficiency and productivity.

As shown in figure 2.5, generally the proposed framework has five modules.

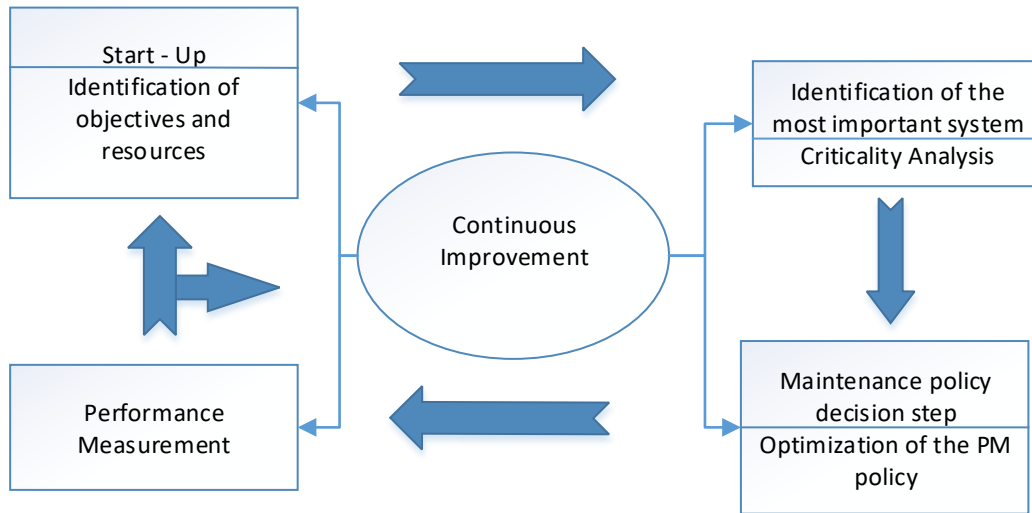


Figure 2.7: schematic overview of the proposed framework (Waeyenbergh and Pintelon, 2002)

Those steps include identify objectives; securing resources; priorities high impact equipment; identify most critical components; selection of maintenance policy; and decide on an appropriate maintenance strategy for selected critical components (Waeyenbergh and Pintelon, 2002).

3. Maintenance Framework 3

Marquez divides maintenance management process as the definition of maintenance strategy from business strategy in order to reduce maintenance indirect cost and the implementation of maintenance, this part is deal about efficiency which is understood as providing better maintenance for the same cost.

An eight blocks maintenance management framework which is organized by four functions developed. This functions are effectiveness; efficiency; assessment; and improvement. Under effectiveness first maintenance objectives and associated KPIs defined. In order to avoid inconsistency of overall business strategy with respect to operational objectives, strategy and

performance measurement balanced score card method used. This helps to set specific KPIs for an organization that align with the strategic objective.

The second is assets prioritized by using probability/risk number analysis. Risk assessment techniques can be used to prioritize assets and to align maintenance actions to business targets at any time. By doing so we ensure that maintenance actions are effective, that we reduce the indirect maintenance cost, the most important maintenance costs, those associated to safety, environmental risk, production losses, and ultimately, to customer dissatisfaction. on some occasions there might not be quantitative data's therefore they put a sequence of questions to classify the assets in "A", "B" or "C" groups. appropriate maintenance strategy specified and high impact weak points to be acted upon.

The third phase is an intervention of higher impact weak points; root cause failure analysis is used. The fourth step is designing the preventive maintenance (PM) plan for a certain system requires identifying its functions, the way these functions may fail and then establish a set of applicable and effective PM tasks, based on considerations of system safety and economy. A formal method to do this is the RCM.

The fifth phase is optimization of maintenance planning and scheduling. Models to optimize maintenance plan and schedules will vary depending on the time horizon of the analysis. Long-term models address maintenance capacity planning, spare parts provisioning and the maintenance/replacement interval determination problems, mid-term models may address, for instance, the scheduling of the maintenance activities in a long plant shut down, while short-term models focus on resources allocation and control. At this stage Monte Carlo simulation used to choose best maintenance policy.

The six phase is execution of the maintenance activities. It has to be evaluated and deviations controlled to continuously pursue business targets and approach stretch values for key maintenance performance indicators as selected by the organization.

On seventh phase the cost of an asset for its entire life span calculated. life cycle cost analysis crucially depends on values calculated from reliability analyses such us failure rate, cost of spares, repair times, and component costs.

Last phase is continuous improvement and maintenance management through e maintenance accurate and precise data flow clearly shown. Total productive maintenance is another way for continuous improvement and maintenance management that is suggested on the maintenance management framework.

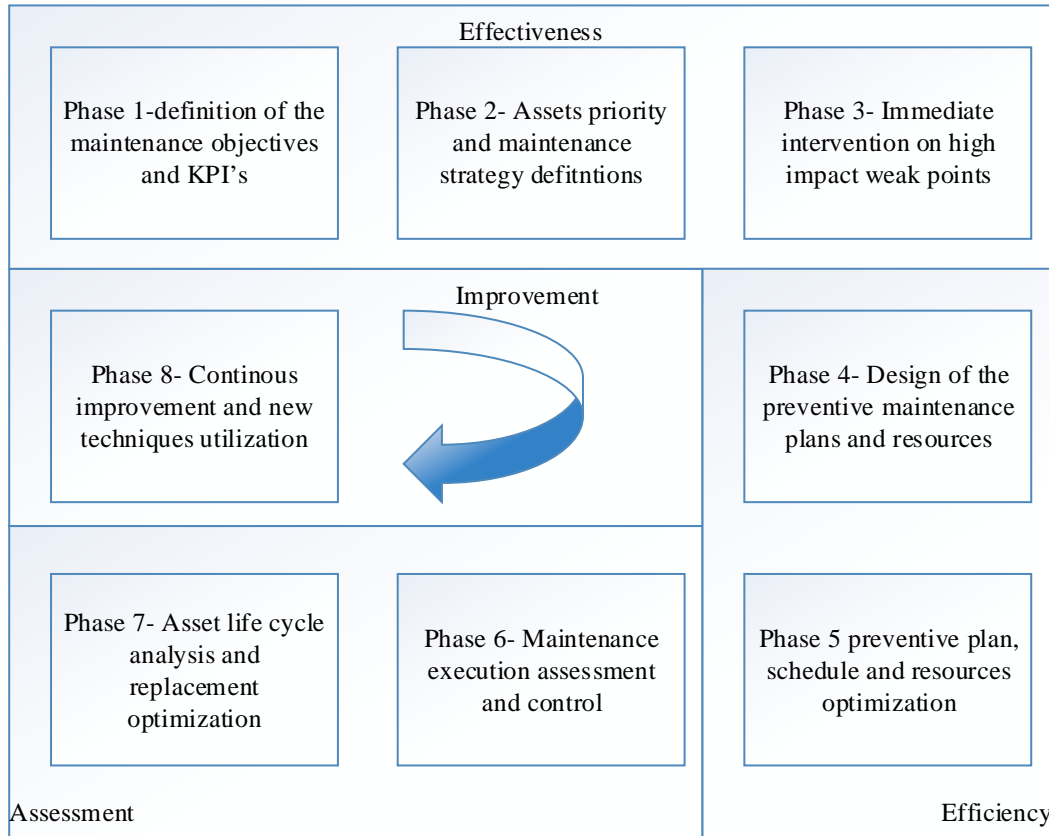


Figure 2.8: Maintenance management framework (Marquez, 2007)

4. Maintenance framework 4.

The developed framework known as CIBOCOF which means Centrum voor Industrieel Beleid Onderhouds Concept Ontwikkelings Framework, or in English, Centre for Industrial Management Maintenance Concept Development Framework. It helps to developed customized maintenance system for a specific company. The framework is a PDCA approach that consists of five modules. The first module is the initiation module, at this stage the available resources, policies and equipment's are analyzed and inventoried. The capabilities of the equipment, the expectations and the objectives of the different assets are recorded.

In the second module, a technical and functional analysis is done. In this module, the installations are split into entities with a distinguishable function called functional systems. These systems are examined and split into components. At the end the Most Important Systems (MIS) and their Most Critical Components (MCC) will be identified.

The third module is selection of maintenance policy for the most critical components that are identified on the previous module. And configuration with additional parameters may be required (i.e., optimization). For this purpose, an extended decision support scheme that enables practitioners to choose the appropriate maintenance policy ‘and’ the right optimization model is provided, the integration of mathematical models in decision trees, which can be compared in some way with decision trees proposed in, e.g., RCM 2 (Moubray, 1997).

The fourth module puts the decisions into practice. Guidelines for the implementation and evaluation are given in this module. Key performance indicators provide management with performance updates. Further analysis of the system performance helps to fine-tune the system.

The last module is a feedback loop. Here, some techniques on how to spread the necessary information through the company are provided.

Generally, the developed framework can be implemented as a whole or each module. Independently

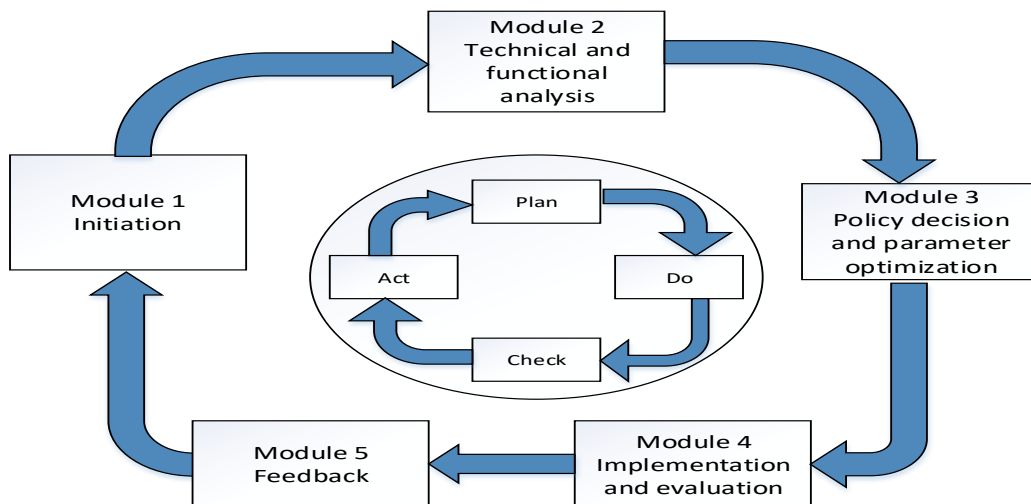


Figure 2.9: CIBOCOF framework (Waeyenbergh, 2009)

5. Framework 5

This framework is developed by Naughton and Tiernan (2012), obstacles to develop individualized maintenance concept are stated. Among those lack of respect for practitioners, lack of respect for experience, lack of management support, lack of process knowledge, fear of change mentioned. They developed a 9-step maintenance framework for developing and implementing an individualized maintenance strategy.

Step 1. Focus on the positives and define one's position: first a company has to make a critical review about its pre-existing maintenance functions by asking important questions and identifying all resources/deficits. To do this team will be created that have a member from all stakeholders. Appreciative inquiry method used and the generative objectives of maintenance clearly stated at this step.

Step 2. Identify constraints and limitation: FMEA table used to rank complexities that affect maintenance. In light of the new identified constraints objectives revised.

Step3: system classification: as per the criticality analysis machines are classified in to different categories, each category critical component identified by using FMEA.

Step 4. Machine classification: once system classified at step 3 further classification of machine and components done here by using sliding scale. This helps to determine the amount of components that require classification with in the classified system. Again FMEA method used and severity of factors of individual components can be ranked on a weighted score system.

Step 5. Policy selection: tacit and explicit knowledge of preexisting maintenance staffs are used to select maintenance policy. More than one policy can be used at a time within the confines of the framework. To identify systems and components that have the biggest impact on pareto analysis performed if there is historical data and if there are no historical data experiences of staffs considered.

Step 6. Aligning performance indicators: plant wide indicators reflect the performance of the maintenance function on three different levels; availability of resources, value or return on investment and technical.

Step 7. Structure maintenance data: as data builds up, the benefits of having an individualized maintenance framework becomes apparent. The quality of recorded data is critical importance. The interaction with computerized maintenance management system should be reliable.

Step 8. Implementation and monitoring: here maintenance framework for entire organization formulated and documented. In order to check formulated framework, it is tested on sample line and monitored intensively. Afterwards, it grown throughout the organization.

Step 9. Feedback: because of its dynamic nature small period adjustment made by conducting continuous review of the individualized framework. Like any continues improvement process each iteration bring more and more gains.

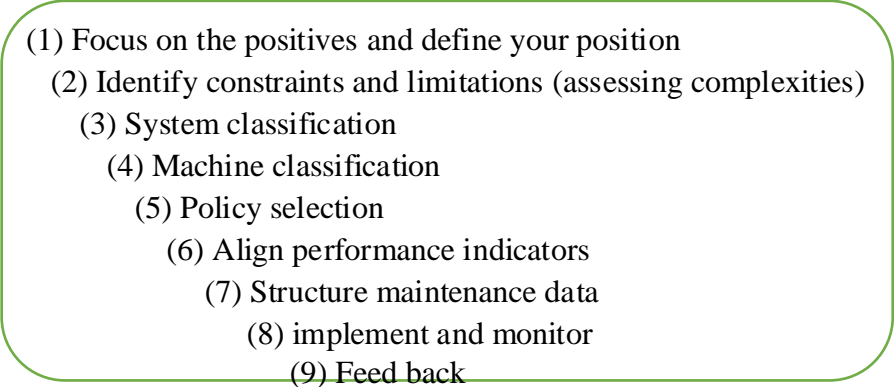
- 
- (1) Focus on the positives and define your position
 - (2) Identify constraints and limitations (assessing complexities)
 - (3) System classification
 - (4) Machine classification
 - (5) Policy selection
 - (6) Align performance indicators
 - (7) Structure maintenance data
 - (8) implement and monitor
 - (9) Feed back

Figure 2.10: Individualized maintenance framework (Naughton and Tiernan 2012)

Limitation of this model is that the model is more dependent on tacit knowledge which is very different from person to person. It might be a false information.

6. Framework 6

It is a proposed maintenance framework by Wireman in the form of a pyramid structure. It consists of 11 blocks consisting of 5 levels. On his framework first level is preventive maintenance program, the second level holds a Computerized Maintenance Management System (CMMS), a work order system, provision of spare parts and the training of maintenance personnel form. The third level consists of predictive maintenance, involvement of operations and reliability centered maintenance (RCM). The fourth level is about the implementation of the total productive maintenance and the application of statistical tools for financial optimization and the fifth addresses continuous process improvement.

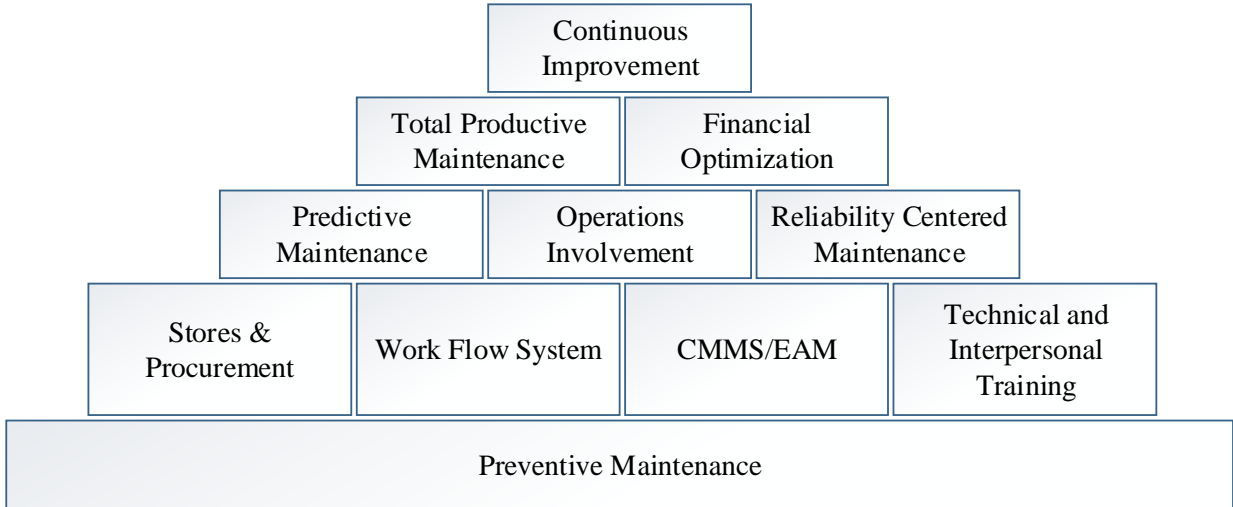


Figure 2.11: Maintenance management framework (Wireman, 2005)

7. Framework 7

Campbell (1998) original cited by Hesham (2015) developed maintenance management framework in to four levels. The first level is development of maintenance strategies for the assets and associated human resource implications of any changes to the working culture. The second level focuses on monitoring and control of individual assets during their lifetime to make sure that they perform to their designed functions in full, development of a measurement system so that performance metrics can be gathered, planning and scheduling of maintenance activities and eight maintenance tactics. The third level covers the application of TPM and RCM for continuous improvement. The fourth level is about maintenance re-engineering. (Hesham, 2015).

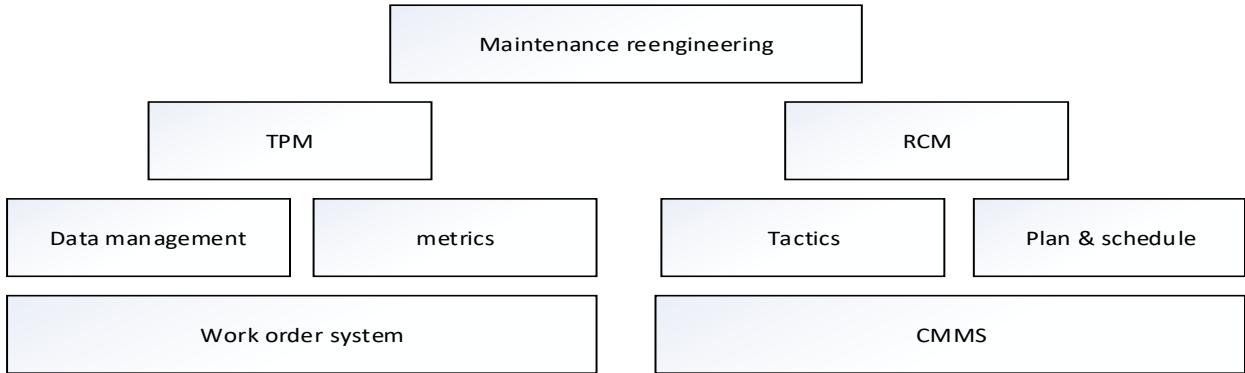


Figure 2.12: maintenance management framework (Hesham, 2015)

8. Framework 8

Another 3-block maintenance management framework proposed by Somesh Kumar Sharma (2013) to redesign the methodology of plant maintenance for effective and continuous maintenance development. Lack of appropriate combination of methodology and maintenance approaches and; the missing link among components of maintenance management such as goals and strategy, human aspects, support mechanism, tools and techniques, organization and also between high performance and competitive advantage are the two major identified literature gaps that are addressed on new developed maintenance reengineering framework. To develop a new framework multi-criteria decision-making phases used.

The first phase an appraisal stage. It is assessing the current status of maintenance in an organization and determining the key performance area (KPA) on the basis of maximum value of weighted deviation. To do this a questionnaire that considers human aspect, critical process, tools and techniques, organization, support systems and goals and strategy developed. The weighted deviation of every factor calculated in order to identify key performance area.

The second phase is decision making phase. Identifying of objectivism resources and most critical failures are completed by following four steps in order to decide the selection of maintenance policy for identified KPA.

On Step 1 three definition of performance from Waeyenbereg and Pintelon, (2004) used, this leads to frame a quantitative objective. The main objective was to capability in the system to increase the output by 50%.

On Step 2 to identified KPA objective, support mechanism such as management information system used to provide accurate maintenance data for spare part provisioning. Accurate data is very important to pinpoint critical plant unit that affects the equipment effectiveness. Also, to understand interdependency among different components of KPA, throughputs and breakdowns a model is developed by using causal loop technology.

On step 3 most critical component with in the critical plant unit identified by using past experience provided by maintenance management information system and anticipated consequences failure delivered from FMECA. The ranking of failure mode is based on most critical failures. The ranking of critical failure is by using global score (G_i).

On Step 4 maintenance policy selected. In order to make right decision about the selection of maintenance policy, the advantage and disadvantages of each maintenance policy needs to be clearly understood. Reliability centered maintenance (RCM), condition-based maintenance (CBM), use based maintenance (UBM), detection-based maintenance (DBM), and design out maintenance (DOM) policies considered to select best fit maintenance policy for identified most critical components.

The last phase the implementation of selected maintenance policy and its evaluation. Therefore, it is a competency building stage. This is a continuous and effective improvement. Benchmarking was the selected method. Benchmarking is a way to achieve world-class maintenance effectiveness. In maintenance it is the search for the best maintenance practice which will lead to exceptional maintenance performance through the implementation of best maintenance strategy. Before starting benchmarking internal environment and external environment analysis performed to figure it out weak areas of the company and to identify comparative companies of best in class that directs the organization to attain high-performance effectiveness standard. This overall analysis will determine the performance gap of the organization with respect to world-class maintenance effectiveness. The identified performance gaps establish the goals for future performance levels that will help in developing benchmark plans. Benchmarking executed in seven steps.

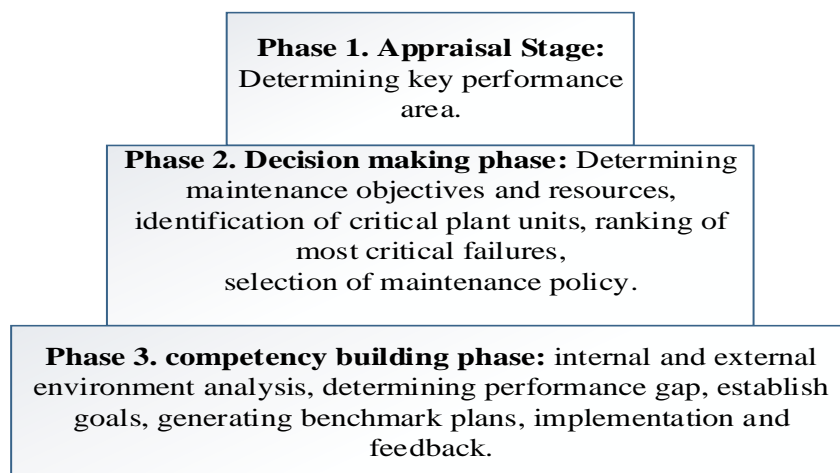


Figure 2.13: maintenance reengineering framework (Sharma, 2013)

However, there is no universally accepted methodology for designing maintenance systems, i.e., no fully structured approach leading to an optimal maintenance system (i.e., organizational

structure with a defined hierarchy of authority and span of control; defined maintenance procedures and policies, etc.). Identical product organizations, but different in technology advancement and production size, may apply different maintenance systems and the different systems may run successfully. So, maintenance systems are designed using experience and judgment supported by a number of formal decision tools and techniques.

9. Framework by Faccio et al 2014

The framework is quantitative that helps to develop optimal maintenance policies, using several cost models, based on simple but relevant costs, like spare parts, labor, missing production costs and other indirect costs. Its focus is limited to failure-based maintenance and use based maintenance policies since these are the most common methods applied in industrial systems. The authors extend their approach also to the statement of predictive maintenance policies for many policies, included CBM. The framework is developed based on a framework developed by Waeyenbergh, 2002 with improvements particularly on final steps regarding the economic evaluation of different maintenance policies. a general quantitative framework to solve planning problems in maintenance policies; its focus is limited to FBM and UBM (in particular Age replacement policy) policies since these are the most common methods applied in industrial systems.

| Phases | Framework Steps | Tools and methodologies |
|---------------------------------------|---|--|
| Equipment analysis | <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">1. Identification of most important system (MISs)</div> <div style="text-align: center;">↓</div> <div style="border: 1px solid black; padding: 5px;">2. Identification of most critical components (MCCs)</div> | <div style="border: 1px solid black; padding: 5px; border-radius: 10px;">Questionnaire, pareto analysis, AHP, fuzzy, FMEA and FMECA</div> |
| Survival data collection and analysis | <div style="border: 1px solid black; padding: 5px;">3. life- time data collection for MCCs</div> <div style="text-align: center;">↓</div> | <div style="border: 1px solid black; padding: 5px; border-radius: 10px;">Data collection sheets, producers data sheets, Reliability SW</div> |
| | <div style="border: 1px solid black; padding: 5px;">4. reliability estimation for MCCs</div> <div style="text-align: center;">↓</div> | <div style="border: 1px solid black; padding: 5px; border-radius: 10px;">Empirical function direct to data(EFDD) & theoretical distribution research (TDR)</div> |
| Decision making process | <div style="border: 1px solid black; padding: 5px;">5. maintenance cost estimation for MCCs</div> <div style="text-align: center;">↓</div> | <div style="border: 1px solid black; padding: 5px; border-radius: 10px;">Industrial accounting and reporting</div> |
| | <div style="border: 1px solid black; padding: 5px;">6. economic evaluation of maintenance policies</div> | <div style="border: 1px solid black; padding: 5px; border-radius: 10px;">Abacus decision tool and decision graphical curves</div> |

Figure 2.14: Integrated framework (Faccio et al., 2014)

Summary: in late 20th century the increased awareness of the importance of maintenance has not yet led to a more structured approach to the maintenance problem. The most widely used concept in practice still seems to be the 'firefighting' approach. While there is a better understanding of the 'invisible' cost caused by poor maintenance, almost no attempts are made to routinely estimate these costs. Even worse, in several industries which gather numerous data on failure history, these data remain largely unused.

2.5.2. Maintenance Management Tools and Techniques

On previous developed frame works different tools and techniques such as balanced scorecard, criticality analysis, OEE, failure root cause analysis, reliability centered maintenance, reliability analysis, critical path method, life cycle cost analysis, critical success factor, current reality tree, fault tree analysis, 5S, reliability blocked diagram, cause and effect diagram etc. used (Marquez 2009, Alzaben 2015, Naughton and Tiernan 2012).

FMEA (Failure Mode and Effect Analysis)

Omdahl, (1988) and ASQC, (1983) originally cited by Ben-Daoolya (2009), Failure mode and effect analysis (FMEA) is an engineering technique used to define, identify, and eliminate known and/or potential problems, errors, and so on from the system, design, process, and/or service before they reach the customer.

Although FMEA started in the aerospace and automobile industry, it found application in various area. It is a systemic methodology intended to perform the following activities:

- i. Identify and recognize potential failures including their causes and effects;
- ii. Evaluate and prioritize identified failure modes since failures are not created equal;
- iii. Identify and suggest actions that can eliminate or reduce the chance of the potential failures from occurring.

Ideally, FMEAs are conducted in the product design or process development stages. However, conducting them on existing products and processes may also yield benefits. Identifying known and potential failure modes is an important task in FMEA.

It is also the most widely understood and applied form of reliability and risk analysis found throughout industry. Given a specific process, FMEA deals with the identification of its failure modes, failure causes and frequencies (reliability), and the effects that might result if any specific failure occurs during the process operation (risk) (Marquez, 2007).

It is widely used by researchers, Vanneste (1995), Waeyenbergh (2002, 2009), Naughton (2012), Alzaben (2015), uses FMEA on their maintenance management framework so as to examines the way the equipment is operated and any failures incurred during its operation to find methods of eliminating or reducing the numbers of failures in the future.

✓ RCA (Root Cause Analysis)

Root Cause Analysis (RCA) is a step-by-step reactive process used to analyze failures and problems down to their root cause. Every equipment failure happens for a number of reasons. There is a definite progression of actions and consequences that lead to a failure. An RCA investigation traces the cause and effect trail from the end failure back to the root cause in order

to determine what happened, why it happened, and more importantly figure out what to do to reduce the likelihood that it will happen again. Causes can be classified as physical, human or latent. The physical cause is the reason why the asset failed, the technical explanation on why things broke or failed. The human cause includes the human errors (omission or commission) resulting in physical roots. Finally, the latent cause includes the deficiencies in the management systems that allow the human errors to continue unchecked (flaws in the systems and procedures) (Ben-Daya, 2006 and Marquez, 2009).

It is conducting of a full-blown analysis that identifies the Physical, Human and Latent Root Causes of HOW any undesirable event occurred. The word "Failure" has been removed to broaden the definition to include such non-mechanical events like safety incidents, quality defects, customer complaints, administrative problems (i.e. - delayed shutdowns) and the similar events.

✓ **FTA (Fault Tree Analysis)**

An effective symbolic logical method of failure analysis of a complex system, Fault Tree Analysis (FTA) can be used to identify the minimal ways in which the top events are linked to the basic events. It taken a top down deductive analysis approach (from product failure to part failure).

✓ **OEE**

OEE is an operational measure and an indicator of process improvement activities within a manufacturing environment. Within this context OEE can be considered to combine the operation, maintenance and management of manufacturing equipment and resources. Nakajima (1988), puts Overall equipment effectiveness as performance measurement that identifies the percentage of manufacturing time that is truly productive.

It is clear that maintenance is not responsible for all production losses experienced by equipment e.g. idle time or setup time. In some cases, e.g. speed and quality loss, maintenance may be a factor but is not the only contributor. For maintenance function to improve performance, it should focus on the portion of indicators they influence. However, the OEE diagram is instrumental in identifying maintenance function related losses. In addition to the maintenance related causes, the OEE metric gives a broader perspective of losses experienced by equipment's and thus supports overall improvement of equipment productivity.

However, the calculation of the OEE as the product of availability, speed and quality performance is not really a complete analysis. Cost and profits are not considered, and so it is not a complete measure by which competitive machines or systems should be compared (Pintelon, 2002). Therefore, while taking OEE as a performance measurement there should be additional analysis that shows the cost effectiveness.

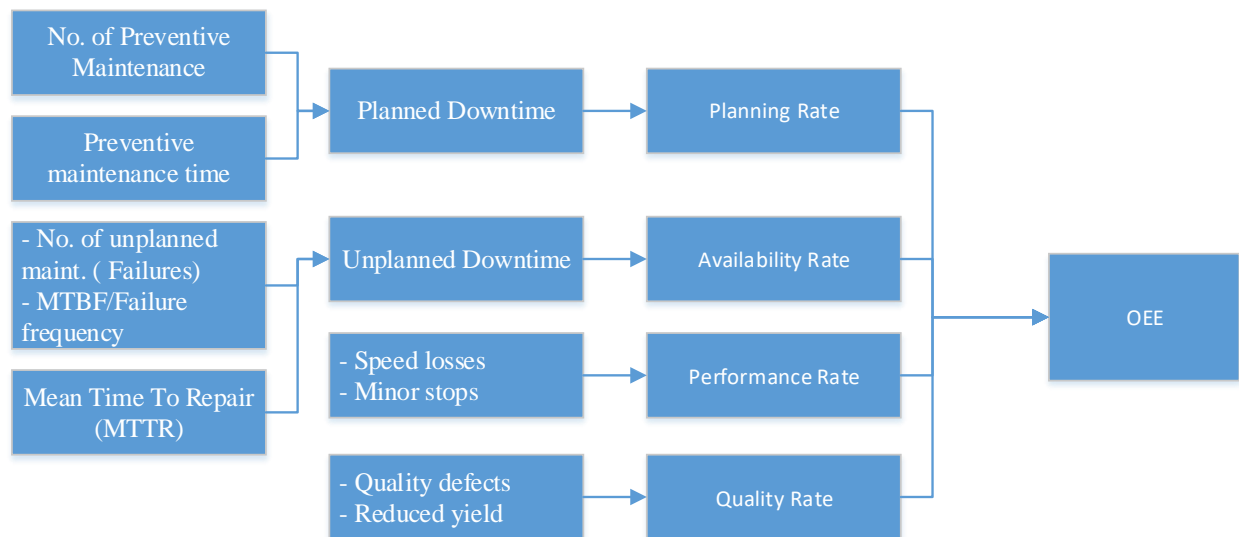


Figure 2.15: OEE diagram (Muchiri, 2011).

✓ Pareto Analysis

The Pareto chart is one of the seven basic tools of quality control. The chart is named after Vilfredo Pareto the Italian economist who noted that 80 % of the income in Italy went to 20 % of the population. The Pareto Principle illustrates the fact that 80 % of the problems stem from 20 % of the causes. A Pareto Chart is a bar graph made of a series of bars whose heights reflect the frequency of problems or causes. The bars are arranged in descending order of height from left to right. This means the factors represented by the tall bars on the left are relatively more significant than those on the right. This helps sort out the important few from the trivial many so that resources and efforts are focused where we can obtain maximum returns. A Pareto chart is a helpful tool in any improvement effort and at different levels. It can be used early on to identify which problem should be studied and later on to narrow down which causes of the problem to address first.

✓ Cause and Effect Analysis

A cause-and-effect diagram is a tool that helps identify, sort, and display possible causes of a specific problem or quality characteristic. It graphically illustrates the relationship between a given outcome and all the factors that influence the outcome. This type of diagram is also called a "fishbone diagram" as it resembles the skeleton of a fish. It is also named "Ishikawa diagram" as it was invented by Kaoru Ishikawa.

A cause-and-effect diagram is a tool that is helpful for identifying and organizing the causes of a problem such as equipment failure. The structure of the diagram provides a very systematic way of thinking about the causes of a particular problem. Some of the benefits of using this tool are as follows:

- ✓ Identifies the root causes of a problem using a structured approach;
- ✓ Promotes group participation and utilizes group knowledge of the process;
- ✓ Uses an orderly, easy-to-read format to diagram cause-and-effect relationships;
- ✓ Increases knowledge of the process by helping everyone to learn more about the factors at work and how they relate to the problem;
- ✓ Identifies areas where data should be collected for further study, if needed; and
- ✓ Constructs a pictorial display of a list of causes organized in different categories to show their relationship to a particular problem or effect.

The steps for constructing and analyzing a Cause-and-Effect Diagram are outlined below:

1. Identify and clearly define the problem or effect to be analyzed. It is a good practice to develop an Operational Definition of the effect to ensure that it is clearly understood by all team members.
2. Draw a horizontal arrow pointing to the right. This is the spine. To the right of the arrow, write a brief description of the effect or problem to be analyzed.
3. Identify the main causes contributing to the effect being studied. These are the labels for the major branches of the diagram and become categories under which to list the many causes related to those categories. Some commonly used categories are as follows:
 - Methods, materials, machinery, and people (3Ms and P);
 - Policies, procedure, people, and plant (4Ps); and

- Another possible significant fifth factor is the environment.
4. For each major branch or category, identify other specific factors which may be the causes of the effect under that category. Identify as many causes or factors as possible and attach them as sub-branches of the major branches.
 5. Identify more detailed levels of causes and continue organizing them under related causes or categories.
 6. Analyze the diagram. Analysis helps you identify causes that warrant further investigation. Since cause-and-effect diagrams identify only possible causes, you may want to use a Pareto Chart to help determine the causes to focus on first.
- ✓ **Maintenance software**

A computerized maintenance management system (CMMS) is a computer software program designed to assist in the planning, management, and administrative functions required for effective maintenance. Computerized maintenance management systems (CMMS), also called computer aided maintenance management (CAMP), maintenance management information systems (MMIS) or even enterprise asset management systems (EAM) (Kobbacy and Murthy, 2008). These functions include the generating, planning, and reporting of work orders (WOs); the development of a traceable history; and the recording of parts transactions. The CMMS helps maintenance in two ways. First, it automates and facilitates existing processes to improve efficiency. Second, the computer can add value to produce benefits otherwise not practically achievable. CMMS and their integration into pre-existing organizations have been proven as an excellent platform to promote communications while improving coordination between different functions in the organization (Huber 1990, Bagadia, 2006 and Dhillon, 2005).

Companies of all sizes can benefit from maintenance software, whether they have a maintenance team of five or five hundred.

There are two common places where CMMS software runs: On a computer at the client's business or on the web. When a business is responsible for running its own CMMS, it is called an on-premises Cloud-based and when the CMMS runs online, it is called a cloud-based CMMS.

Benefits of a CMMS

- **Less work outages:** It is easy to do preventive maintenance which means there are less surprise breakdowns.
- **Better accountability:** Quickly see if a technician did their work on time and get alerted when a task is complete.
- **Less overtime:** Better scheduling means that your team isn't sitting idle or working overtime, which means work can be distributed evenly.
- **Information capture:** Technicians can record problems and solutions, so this information is captured for others to use.
- **Savings on purchases:** Inventory planning features give you the time to shop around for spare parts pricing, instead of having to buy in a hurry.
- **Certification and analysis:** A full record of assets and performance helps managers analyze energy usage and plan maintenance spend.

Every industry needs maintenance and CMMS software helps plan and manage that maintenance. Production maintenance, facility maintenance, fleet maintenance are major key users of CMMs.

2.6. Maintenance and Performance

In order to achieve world-class performance, more and more companies are replacing their reactive, "fire-fighting" strategies for maintenance with proactive strategies like preventive and predictive maintenance and aggressive strategies like total productive maintenance. While these newer maintenance strategies require increased commitments to training, resources and integration, they also promise to improve performance. Effective maintenance is also critical to many operations. By keeping the productivity performance of plants and machineries in a reliable and safe operating condition this is due to that the performance and competitiveness of manufacturing companies is dependent on the reliability, availability and productivity of their production facilities. There is consensus among authors that equipment maintenance and system reliability are important factors that affect organization's ability to provide quality and timely services to customers and to be ahead of competition. Maintenance function is therefore vital for sustainable performance of any manufacturing plant (Swanson, 2001, Alsyouf 2007, Muchiri et al., 2011 and Parida et al., 2015).

Maintenance provides critical support for heavy and capital-intensive industries proficiency to optimize its production system in order to meet its long-term objectives. Generally, a production system in which maintenance is not given attention may easily lead to the system producing defective product as a result of machine defect. Therefore, Maintenance contributes more than ever to the achievement of these objectives. Indeed, proper maintenance does not only help to keep the life cycle cost down; it also contributes positively to the overall performance of the company. (Enofe and Aimienrovbiy, 2010, Pintelon 2002). Also, another research shows significant support was found for positive correlation between TPM and business performance. Business performance of TPM firms was significantly superior to the non-TPM firms (Brah and Chong, 2007).

While investing on maintenance, implementation might be a cost at the earlier stage of implementation because it is hard to measure and follow up its impact on company's business. Nevertheless, its role in improving company productivity profitability is indispensable. Thus, maintenance is a profit center rather than a cost center (Enofe and Aimienrovbiy, 2010). By including an economic indicator, the maintenance personnel are immediately involved in the strategic overall goal of the organization, and their contribution towards enterprise profitability performance can be quantified (Naughton, 2012).

According to Al-Turki (2011), maintenance management are the activities of planning, organizing, implementing, monitoring and controlling in order to sustain a certain level of availability, value and reliability of the system and its components (assets) and its ability to operate to a certain standard level of quality. Therefore, the choice of the maintenance management practice applied impacts heavily on the performance of the firm. The main measures of operational performance of a firm are reliability, maintainability, productivity, efficiency, availability and production per unit cost, among others (Wilson, 2002). Since Firm's maintenance costs are normally high (Al-Turki, 2011) application of best maintenance management practices can boost a firm's operational performance (Gupta et al., 2005). The maintenance management practices which offer better operational performance therefore need to be established in research.

2.7. Maintenance performance measurement

Effectiveness of maintenance and its quality need to be measured for the justification of investment in maintenance. Breakdowns and downtime have an impact on the plant capacity, product quality and cost of production, as well as on health, safety and the environmental issues (Parida et al.,

2015). The process of maintenance performance measurement (MPM) development should be guided by the integration of critical success factors (CSF), which are derived from the overall organizational strategy and this can realize by improved understanding of the operation and maintenance process, through identification, development and implementation of appropriate quantitative and qualitative performance indicators (PIs) for the MPM system. PIs are used to highlight deficiencies in a company and to analyze it further to find the problem that is causing the indicator to be low. If properly used, performance indicators will show an organizations improvement area. PIs could be broadly classified as leading or lagging indicators. A leading indicator is one that warns the user about objectives beforehand and A lagging indicator normally changes direction after economy has. they indicate the condition after the performance has taken place. The establishment of a link between the lagging and the leading indicators helps to monitor and control the performance of the process, and the indicators to be linked are selected in line with the chosen maintenance strategy (Wireman, 1998, Kumar and Ellingsen, 2000).

Feurer and Chaharbaghi, (1995) as originally cited by Parida (2015), performance measurement systems are used differently depending on their application, like financial reports, costing systems, performance appraisal and reward systems, customer satisfaction, competitor ranking and for measuring improvement of the organization, besides productivity improvement and optimization. In addition the efficiency and quality of the maintenance need to be measured through maintenance performance indicators (MPIs) and key performance indicators (KPIs), for justification of investment in maintenance (Parida and Chattopadhyay, 2007).

Kumar et al. (2011) have discussed types of indicators, leading versus lagging and hard versus soft, besides their linkage to KPIs extensively. most evidently with the production function. Summery is below. However, performance indicators are not defined in isolation, but should be the result of a careful analysis of the interaction of the maintenance function with other organizational function (Muchiri, 2011).

To restrict the literature review, the PM frameworks is divided into traditional accounting based, and multi-criteria frameworks. The multi-criteria PM frameworks are considered under balanced and multi-criteria, and, cause and effect relationship PM frameworks. These entire PM frameworks are relevant to the MPM framework conceptually as the MPM framework considers the integrated and holistic aspects of the organization, and forms part of the business measurement.

As per Parida et al., (2015) Different authors have modified, developed and suggested frameworks considering non-financial measurements and intangible assets to achieve competitive advantages by the organizations. MPIs are linked to the reduction of downtime, costs and wastes, and the enhancement of capacity utilization, productivity, quality, health and safety (Parida and Kumar, 2004). On Parida et al., (2015) literature review of maintenance performance management, there are around 26 performance measurement frameworks with different measures, indicators and criteria's. maintenance performance indicators can be economic indicators or technical indicators.

2.7.1. Performance indicators, drivers and killers

Well-defined performance indicators can potentially support identification of performance gaps between current and desired performance and provide indication of progress towards closing the gaps. (Muchiri et al., 2011). Three types of performance indicators found on literatures, leading indicators that measures inputs as a process it measures future events, Coincident indicators that shows the performance while occurring and lagging indicators that measures output as a process it measures events that have already occurred. (Parida, 2015). The leading indicators are even more important than lagging indicators because they have the potential to avoid unfavorable situations from occurring. performance killers are process inputs that leads to poor performance.

Summary of lagging and leading indicators described on table 2.4. (Muchiri et al., 2011).

Table 2.4: Leading and lagging indicator

| Category | | Measures / Indicators | UNITS | Description | Recommended Targets |
|--------------------------------|---------------------|--------------------------------|-------|--|------------------------|
| performance leading indicators | Work Identification | Percentage of Proactive work | % | Man-hours envisaged for proactive work/Total man hours available | 75% - 80% |
| | | Percentage of Reactive work | % | Man-hours used for reactive work/Total man-hours available | 10% - 15% |
| | | Percentage of Improvement work | % | Man-hours used for improvement & modification/Total man -hour available | 5% - 10% |
| | | Work request response rate | % | Work requests remaining in 'request' status for <5days/Total work requests | 80% of requests |
| | Work Planning | Planning Intensity/Rate | % | Planned work / Total work done | 95% of all work orders |

| | | | | | |
|---------------------------------|--------------------------------|--------------------------------------|-----------------|---|--|
| | | Quality of planning | % | Percentage of work orders requiring rework due to planning/All WO | < 3% of all WO |
| | | Planning responsiveness | % | Percentage of WO in planning status for <5days/ All WO | > 80% of all WO |
| | Work scheduling | Scheduling Intensity | % | Scheduled man-hours/ Total available man-hours | > 80% of available man-hours |
| | | Quality of scheduling | % | Percentage of WO with delayed execution due to material or man-power | < 2% |
| | | Schedule realization | % | WO with scheduled date earlier or equal to late finish date/All WO | > 95% of all WO |
| | Work Execution | Schedule Compliance | % | Percentage of work orders completed in scheduled period before late finish date | >90% |
| | | Mean Time To Repair | Hours | Total Downtime/No. of failures | |
| | | Manpower Utilization | % | Total Hours spent on tasks / Available Hours | > 80% |
| | | Manpower Efficiency | % | Time Allocated to Tasks/Time spent on tasks | |
| | | Work order turnover | % | No. of completed tasks/ No. of received tasks | |
| | | Backlog size | % | No. of overdue tasks/ No. of received tasks | |
| | | Quality of | % | Percentage of maintenance work requiring rework | < 3% |
| | performance lagging indicators | measurement of equipment performance | No. of failures | No. | Number of failures classified by their consequences; operational, non-operational, safety... |
| Failure per breakdown frequency | | | No. / unit time | No. of failures per unit time(a measure of reliability) | |
| mean time between failure | | | Hours | meantime between failure- a measure of reliability | |
| Availability | | | % | $MTBF/(MTBF + MTTR)= \text{uptime}/ (\text{uptime} + \text{downtime})$ | |
| overall equipment effectiveness | | | % | Availability * Performance rate* Quality | |
| Measures of cost | | Direct maintenance cost | \$ | Total corrective and preventive cost | |
| | | breakdown severity | % | Breakdown cost / Direct maintenance cost | |

| | | | |
|--|---|----------------------|---|
| | Maintenance intensity | \$ / Unit production | % of maintenance cost per unit of products produced in a period |
| | % of maintenance cost component over manufacturing cost | % | Maintenance cost / Total manufacturing cost |
| | ERV (Equipment replacement value) | % | Maintenance cost / New condition value |
| | Maintenance stock turnover | No. | Ratio of cost of materials used from stock with in a period |
| | Percentage cost of personnel | % | Staff cost/total maintenance cost |
| | Percentage f cost subcontractors | % | Expenditure of subcontracting / Total maintenance cost |
| | Percentage cost of supplies | % | Cost of supplies / Total maintenance cost |

Leadership support is the most important factor in the success of maintenance performance management implementation.

Different performance management approaches discussed on literature review of maintenance performance management. Among those approaches, few of them listed below

- Value driven performance measure
- Balanced score card approach based
- Integrated maintenance performance measurement system corporate strategy and balanced score card
- Multi criteria hierarchical maintenance performance management framework
- E-Maintenance framework
- plant/ equipment health management framework
- strategic asset performance approach.

2.8. Maintenance in food and beverage industry

Maintenance is crucial in any organization. Without proper maintenance, assets deteriorate over time causing a loss in quality of the output produced. More importantly, it can also impact the safety of the asset or the people that operate it. Traditionally, maintenance has been viewed as a

cost center in an organization; it costs money to hire maintenance technicians and purchase the spare parts to keep systems running smoothly. Too often, senior executives ignore the added value maintenance can bring to an organization such as:

- A reduction in reactive maintenance costs
- Reducing costs to restart production after a breakdown
- Limiting production scrap
- Costs of downtime such as missed orders and lost revenue
- Customer perception/satisfaction
- Improved quality of products
- Reduced environmental impact

Not surprisingly, maintenance can add economic value to a business by delivering maximum availability at the lowest possible cost. To view maintenance as a value driver, senior executives must move from cost-based thinking to value-based thinking. These pressures have given firms worldwide the motivation to explore and embrace proactive maintenance strategies over the traditional reactive firefighting methods (Ahuja and Khamba, 2007; Sharma et al., 2005).

Food and beverage industries are producing perishable products. When equipment is well-maintained, the safety standards of the food being processed will be high. On the contrary, ill-maintained equipment will break down more often during manufacturing and processing, thus compromising the integrity of the production processes and the food being produced. Due to this reason, having an appropriate maintenance system is critical

2.8.1. Maintenance Challenge in Food and beverage Industry

Industry by itself has its own set of problems and issues. But food and beverage manufacturers probably face more hurdles than those in general industry. Since they are producing something humans are going to eat. There's a higher level of scrutiny in this industry. Therefore, manufacturers of edible products face a diverse world of significant challenges, including stringent government regulations, harsh working conditions and complex equipment that can be difficult to maintain. There are different challenges to implement effective maintenance in an organization. Phogat and Gupta (2017), identifies the major problems which is listed on table 2.2.

Table 2.5: Problems on maintenance operation

| S.No. | Problems in maintenance operations | References |
|-------|--|---|
| 1 | Lack of benchmarking | Adebanjoetal.(2010),Singh(2011),Shaaban and Awni(2014) |
| 2 | Lack of communication and information | Mohamed (2005), Leong et al. (2012) |
| 3 | Lack of empowerment | Yongtao et al. (2014), Poduval et al. (2015) |
| 4 | Lack of teamwork | Rolfesen and Langeland(2012),Aspinwall and Elgharib(2013) |
| 5 | Lack of commitment of employees toward maintenance | Singh and Ahuja (2010) and Mosadeghrad (2014) |
| 6 | Lack of training | Singh et al, (2013), Mosadeghrad (2014) |
| 7 | Lack of proper strategic planning and implementation | Singh et al.(2010),Abreu et al.(2013),Mosadeghrad(2014), Ding et al. (2014) |
| 8 | Lack of top management support | Kodali et al. (2009), Singh et al. (2008), Kumar et al. (2015) |
| 9 | Lack of awareness about safety and health | Grusenmeyer (2010), Singh et al. (2013), Narayan (2012) |
| 10 | Lack of effective performance measurement | Parida and Kumar (2009), Lad and Kulkarni (2010a) |
| 11 | Lack of measurement of OEE | Pophaley and Vyas (2010), Lad and Kulkarni (2010b) |

Food safety regulations affect each manufacturer in a different way. One is Hazard Analysis and Critical Control Point (HACCP). This minimum requirement helps the manufacturer to provide hazard free safe products to consumer. Hazards can be physical, biological and chemical agents. Each manufacturer is responsible for creating its own inclusive set of guidelines, including a good maintenance system to protect unintentional contamination of the product. Food manufacturers will also need to consider equipment upgrades to eliminate surfaces prone to rust and corrosion - breeding points for bacteria and pathogens. (ISO22000:2005). Therefore, having effective and efficient maintenance management system is mandatory in order to fulfill the food safety management requirements.

2.9. Summary and gaps from literature

A maintenance concept should consider all relevant factors of the situation on hand. As such, it will have to be tailored to the needs of the company in question. This means that the ‘optimum’ maintenance concept will be unique for each company. Moreover, since industrial systems evolve

rapidly, the maintenance concept will also have to be reviewed periodically in order to consider the changing systems and the changing environment.

A lot of maintenance concepts are described in literature, offering interesting and useful ideas, most of them are highly resource intensive in terms of manpower and management attention. Applying a standard concept readily available from literature is not always the best thing to do. Moreover. This makes the development and implementation of a maintenance concept difficult in practice. However, researchers on this area (Wayenbergh and Pinteon, 2002, 2009, (agree by developing a customized maintenance concept the above shortcomings will be addressed that the new maintenance concept must fit the objectives and the culture of the company, as well as the existing maintenance organization).

1. Available frameworks are very few in number since many of the concepts are only valid for a special class of equipment or a specific industry.
2. Till now no framework found for food and beverage industry.
3. Literature review revealed among other frameworks, maintenance framework developed by Marqueze, (2007) is relatively better than other frameworks. However, it has limitation on work flow system and data management.

Therefore, the framework that is developed in this paper addresses the above identified gaps.

Chapter 3: Research Methodology

3.1. Introduction

In this chapter detail steps elaborated to conduct the study. Mainly it has four parts data collection, sampling and sample size and data presentation and analysis.

3.2. Data collection

Primary and secondary data collection methods used. Data collection section is composed of literature review, observation, interview and questionnaire.

Literature review: intensive literature review conducted to understand details about maintenance the subject matter. It starts with terms and concepts definition, evolution of the maintenance concept, relation of maintenance and company performance, types of maintenance models, challenges of maintenance in food and beverage industry and maintenance management tools. Sources of literature are journals, forums, books, previous thesis works.

Observation: it can be made under two conditions, Natural and controlled. Observing a group in its natural operation rather than intervening in its activities is classified as observation under natural conditions. Introducing a stimulus to the group for it to react to and observing the reaction is called controlled observation (Renjit, 2011). Therefore, in order to understand facts about the case company practical production process, maintenance activities verses procedures, information system management including logbooks, work orders and facilities non-participant observation conducted under natural working condition. Observation conducted a total of 5 times. During this period of time, real practices of maintenance compared with answers of questionnaires, and other related activities.

Questionnaire: To gather data about the organization and maintenance management practices adopted by Asku plc., an open ended and closed types of collective questionnaire developed. The questionnaire has five parts that cover the following topics. 5 scale liker scale will be used.

Section I - General Information: This section aims to identify the company profile, activity, and number of employees, number of equipment under the responsibility of the maintenance area and origin of the company.

Section II - Maintenance management: identify the techniques, strategies and management tools used for maintenance.

Section III – Maintenance Indicators: identify the degree of use of performance indicators in the management of maintenance.

Section IV - Procedures and Maintenance Plans: identify the degree of organization and planning of maintenance in the company.

Section V - Maintenance Staff: assess the degree of organization, development and training of the maintenance staff.

40 questionnaires distributed with a response rate of 75%.

Interview: semi structured interview followed to collect necessary information from employees on managerial level.

Maintenance and engineering department manager and training coordinator has been interviewed.

3.3. Sampling and sample size:

Among the types of sampling techniques, random, non-random and mixed sampling techniques for this study non-random sampling is selected which is purposive sampling is selected. This type of sampling is extremely useful to construct a historical reality, describe a phenomenon or develop something about which only a little is known. This sampling strategy is more common in qualitative research. It is also possible to use this technique in quantitative researches (Renjit, 2011). The purpose of sampling in quantitative research is to draw inferences about the group from which the sample will be selected, whereas in qualitative research it is designed either to gain in-depth knowledge about a situation/event/episode or to know as much as possible about different aspects of an individual on the assumption that the individual is typical of the group and hence will provide insight into the group. Due to the above reasons it is suitable for this study.

Sample size: there are a total of 32 employees under maintenance department. Therefore, all maintenance and engineering staffs will be participating for data collection. 23 production department employees will be participating so as to get more or less a full understanding of

employees and machine history. In addition to machine operators and technical staffs to understand impact of maintenance on quality, 5 staffs from quality control and assurance department selected. Therefore, total number of participants with their position will be as follow.

Table 3.1: Participants for data collection with their respective position

| S. No. | Department | Position | Quantity |
|---------------------------|--|--|----------|
| 1 | Admin. | Plant Manager | 01 |
| 2. | Maintenance and Engineering | Maintenance and engineering department manager/Deputy plant manager | 01 |
| | | Supervisors (Maintenance supervisor, utility supervisor and workshop supervisor) | 03 |
| | | Mechanics (Operator mechanic, mechanic, senior mechanic) | 20 |
| | | Electrician (Junior electrician, senior electrician) | 3 |
| | | Experts | 2 |
| | | Workshop staffs (machinist and winder) | 2 |
| 3. | Production Department | Line supervisor and shift leader | 4 |
| | | Machine operators | 19 |
| 4. | Quality Control and Quality Assurance Department | Supervisor (Quality Control supervisor, Quality Assurance supervisor) | 02 |
| | | Line chemist | 03 |
| Total number of employees | | | 60 |

3.4. Data Presentation and Analysis

Data collected sorted, organized and coded. To analyze data's statistical tools such as tables, graphs and charts used.

On previous maintenance management frameworks different tools and techniques used to develop the framework. Among those tools FMEA, histograms, quality control charts, OEE, balanced score card, failure root cause analysis, reliability centered maintenance, reliability analysis, critical path method, life cycle cost analysis, critical success factor, current reality tree, fault tree analysis can be mentioned (Marquez et al., 2009, Alzaben, 2015). Therefore, for this study the below four tools selected and used for framework development.

- Among different reliability analysis tools FMEA used because it has a potential to anticipate and prevent problems, reduce cost and achieve highly reliable products and processes. To conduct the analysis a group with 5 team members formed. Those team members are from Maintenance department, Production department and quality department. It is determined by risk probability number.

$$\text{RPN} = \text{Severity} * \text{Occurrence} * \text{Probability}$$

Where severity, occurrence and detectability are a value from 1 to 10. It is found on appendix C.

- to Overall equipment effectiveness (OEE) will be used to determine focus area with maintenance problems.

$$\text{OEE} = \text{Availability} * \text{Performance} * \text{Quality}$$

After completion of data analysis maintenance management framework and implementation procedure developed.

Initial step to develop a framework was understanding the subject matter, understand how the concepts are related, review different frameworks that are relevant for the study, study case company in order to understand existing working condition and compare with literatures, select, develop or modify existing methods that can fit to the case company. After developing an implementation step, discussion was help technical experts and managers to validate the framework.

3.5. Research framework

The research starts by doing preliminary research assessment and gap identification. The next step is formulation of problems and objectives to do this literature survey performed and also experts in this area consulted. Therefore, at this stage research questions, objectives, problem statements

developed and modeled and also expected results forecasted. After formulation of problems and objectives intensive literature reviews done so as to have a detail knowledge on maintenance, maintenance practice in beverage industry and any knowledge related to the subject matter.

Next research design and methodology established by listing required steps of the process, preparing appropriate data collection tools. As per selected data collection method and analysis tools data collected, presented and analyzed. Then results discussed by interlinking with previous studies. Here improvement areas clearly identified and new maintenance management model developed. The framework address identified weakness throughout Asku's maintenance management system. At this stage implementation procedure prepared. At last stage there will be conclusion and recommendation as per the result of the paper.

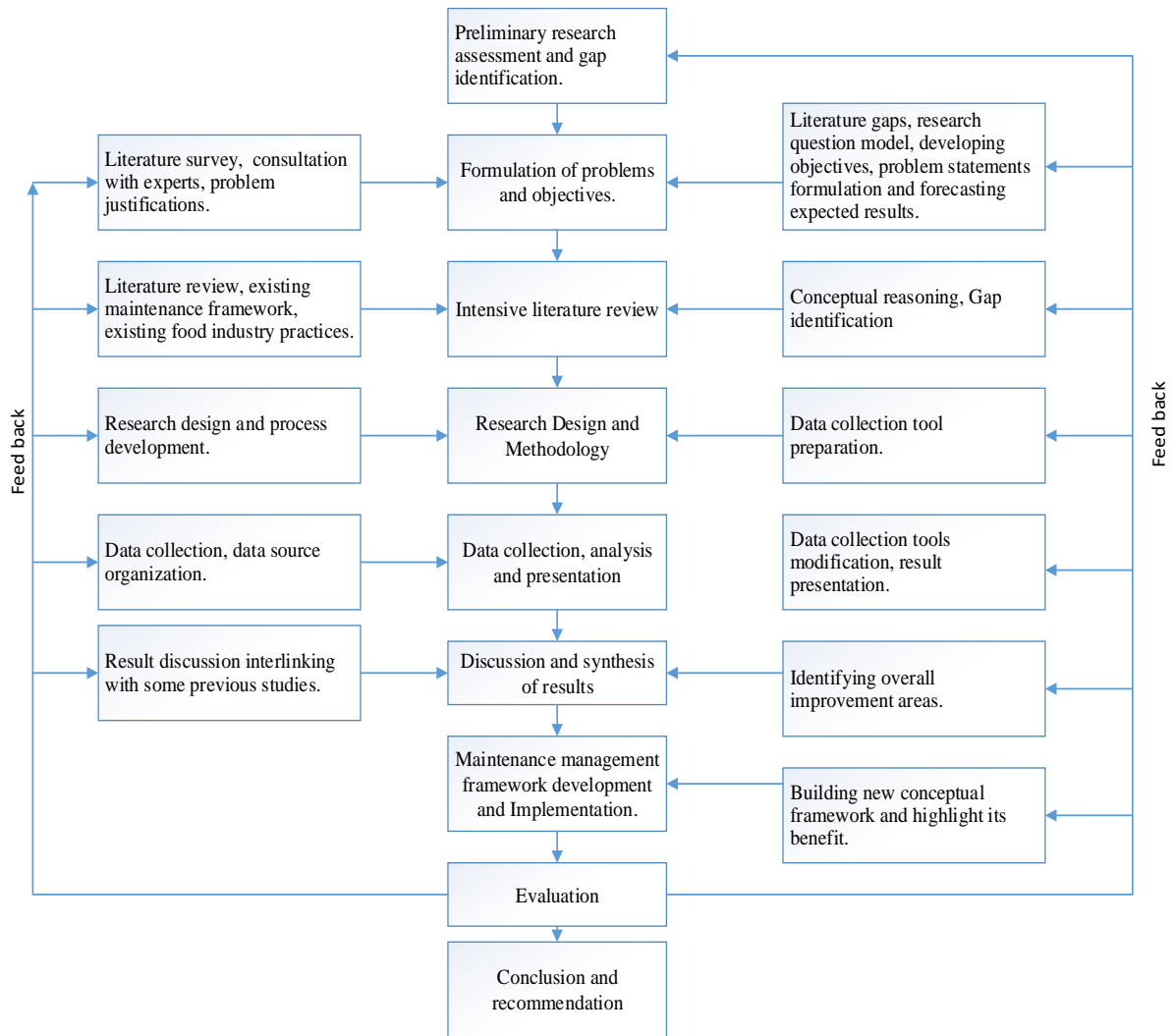


Figure 3.1: Graphical representation of research methodology

Chapter 4: Company Profile

ASKU PLC is one of the industries under ABIG (ASKU and Berhane Investment Groups) engaged in the manufacturing sector headquartered in Addis Ababa Ethiopia. ASKU PLC, mainly focused in the food and beverages line of business strives to become the leading Food and Beverages Company in Ethiopia by making Food and Beverages that are people's preferred choice and at the same time build a high performing organization which will play a key role in making Ethiopia food and beverages exporting nation.

Currently our company is producing bottled water under the brand Aquaddis in five different sizes and carbonated soft drink (CSD) in five different flavors: RC Edge, RC Cola, RC Orange, Royal Tonic and RC lemonade. In addition, we are in the process of introducing Orange, Fruit punch and Mango juice in two different sizes.

Both carbonated soft drink and juice are produced using USA concentrate imported through our franchise agreement with Cott Beverage Inc, which is a company based in Columbus, Georgia, USA. ASKU PLC is the exclusive bottler of Cott product which is the world largest supplier of private label CSD for retailers with approximately 4,000 employees. Cott operates soft drink, Juice, water and other beverage bottling facilities in the United States, Canada, the United Kingdom and Mexico and sells beverage concentrates in over 50 countries around the world.

ASKU PLC has two separate facilities in Addis Ababa and Burayu under construction for edible oil refining and dairy product processing.

Vision

- To become the leading food and Beverage Company which will play a key role in making Ethiopia food and beverage exporting nation.

Mission

- To produce favored brand by focusing on food safety and meeting the highest standard of quality and freshness cost effectively.
- To continuously build on our knowledge and experience coupled with technology and innovation to provide premium quality food and beverage which are preferred by all generations.

- To adhere to the highest standards of corporate social responsibility and the preservation of the environment
- To continuously work with our associates and provide them with opportunities for learning, professional growth and a better quality of life.

Core value

- Food safety, Quality and freshness
- Cost effectiveness
- Teamwork
- Integrity and trust
- Commitment to society and the environment

4.1. Organizational Structure

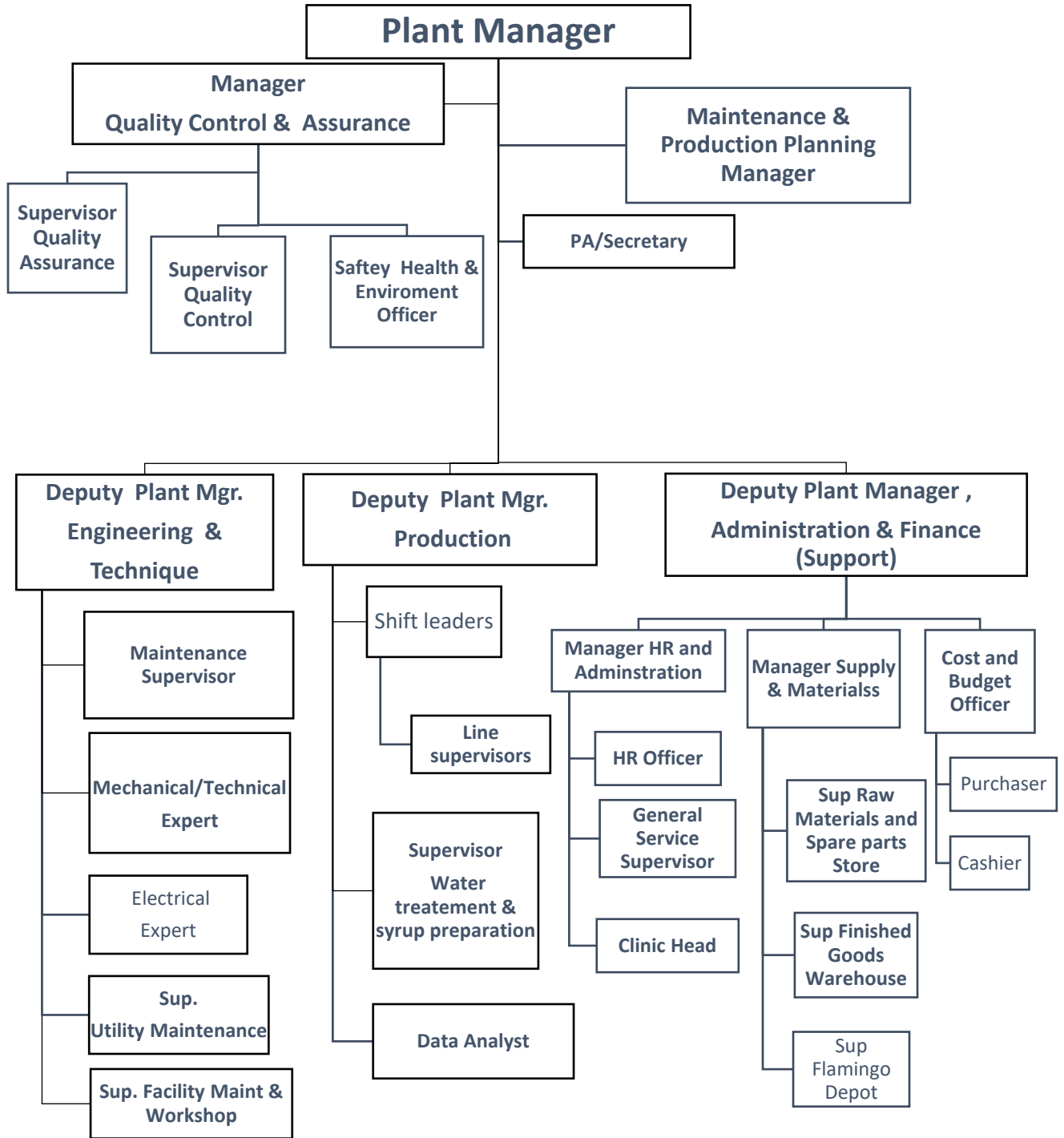


Figure 4.1: Organizational Structure

Production line.

- Water treatment and syrup preparation: in this work center there are eight machine centers for physical, chemical and biological hazard treatments for raw water; sugar melting, filtering and syrup preparation for carbonated and soft drink preparation and chemical cleaning tanks.
- Blow fill section: this work center consists of five different machine centers.
 - I. Blower machine center – components include blower machine, preform hopper and elevator and air conveyor.

Stretch blow molding machine: - the core function of this machine is to process semi-processed product which is called preform in to the required empty plastic bottle. The machine has mainly four systems.

- ✓ Master bottle blowing unit which is consists of mold clamping unit, stretch and seal unit, mold thickness adjusting unit and centralized system lubricate system.
- ✓ Preform reheating units-
- ✓ Pneumatic system
- ✓ Electric system and control system.
 - II. Filler machine Center- components include rinser machine, filler machine and capper machine.
 - III. Neck sleeve machine center- in this machine center automatic neck sleeve machine and its conveyor includes.
 - IV. Labeler machine center- here automatic labeling, shrinking tunnel and cate code machine included.
 - V. Packer machine center- group packing machine and its conveyor are parts of the machine center.

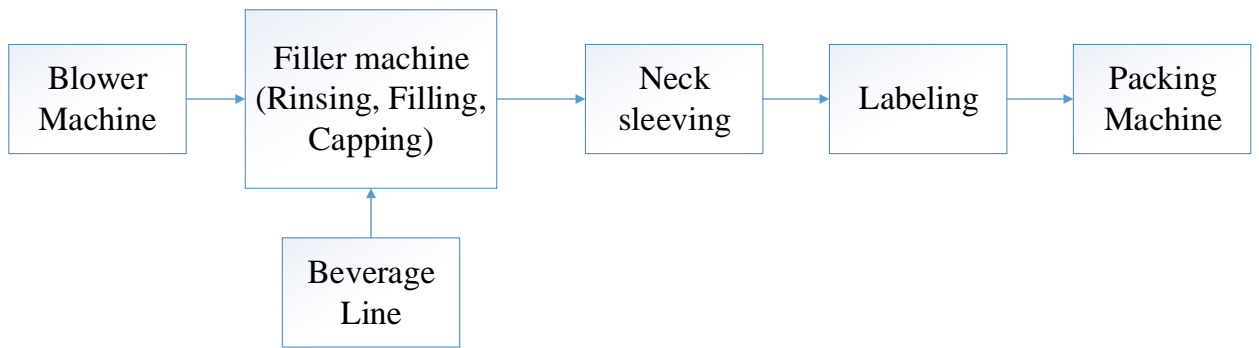


Figure 4.2: Machine layout

Chapter 5: Data Analysis and Discussion

5.1. Data Presentation and Analysis

Collected data presented and analyzed below.

- General information: maintenance planner, maintenance supervisor, shift leader, mechanic and senior mechanic participated. 63.5 % of respondents has maximum of 7 years work experience. 100 % of respondents work at Asku plc maximum of 7 years. They have educational background level 3, diploma and bachelor degree.

Table 5.1: General information

| Position | maintenance planner, maintenance supervisor, shift leader, mechanic and senior mechanic | | | |
|--|---|------------|-------------|-----------|
| Total year of experience | 0 - 3 yrs. | 4 - 7 yrs. | 8 - 11 yrs. | > 11 yrs. |
| Number of employees (in %) | 37.5% | 25% | 25% | 12.5% |
| Year of experience at Asku plc. (in %) | 75% | 25% | | |
| Educational background | BSC Diploma level 3 | | | |

- Machine Performance is expressed in terms of overall equipment effectiveness (OEE). OEE is calculated as;

$$OEE = Availability * Performance * Quality$$

13 months' data from September, 2016 up to September, 2017 taken to calculate OEE for each machine. Table is attached on appendix B1. OEE of each machine shown from Figure 5.1 up to 5.

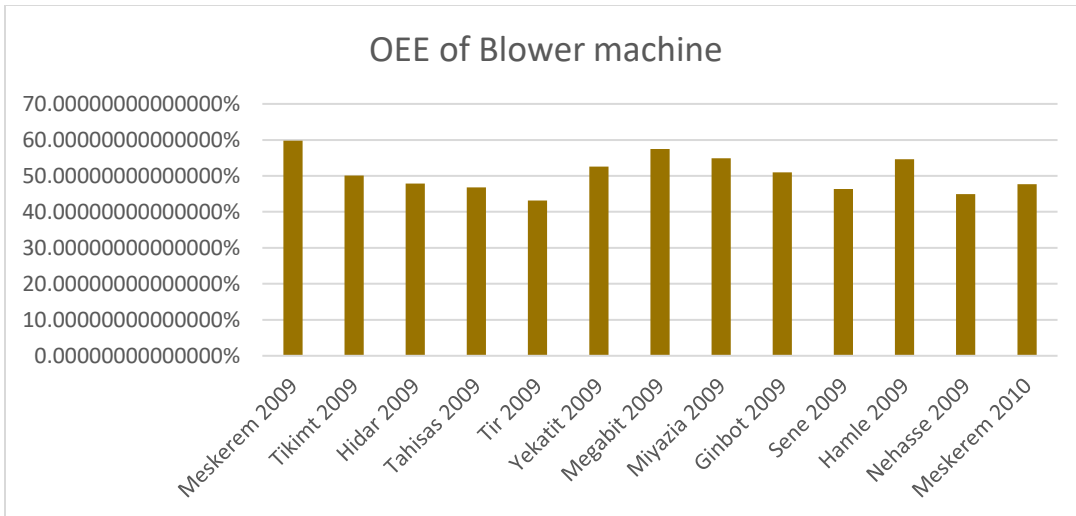


Figure 5.1: Rate of machine performance

Figure 5.2 shows OEE of filler machine. The main contributor for lower OEE is its performance. This happens because of availability of bottles to be filled and technical downtime registered on it. Data used for OEE calculation is attached on Appendix B2.

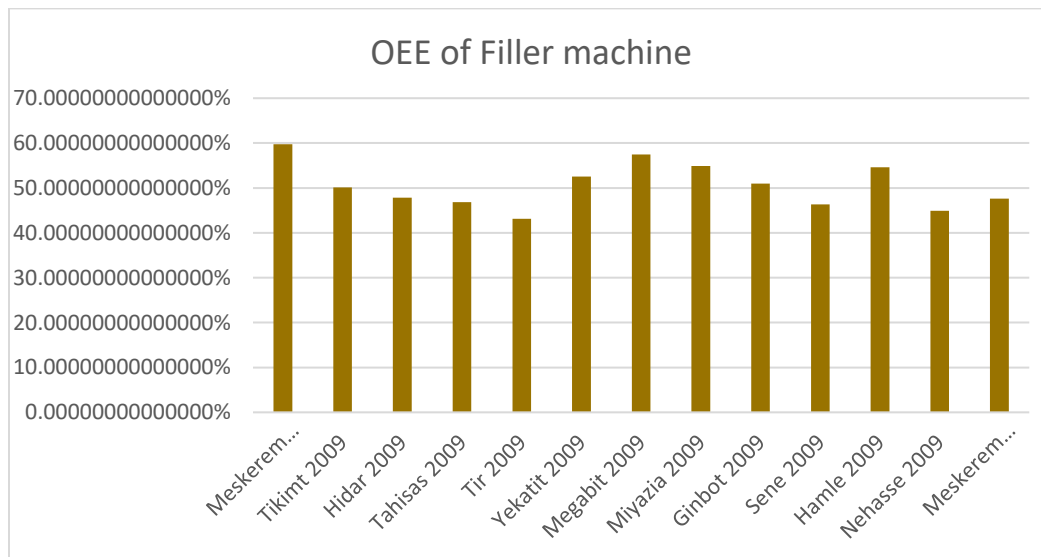


Figure 5.2: OEE of filler machine

The highest OEE of packer machine was 65 % this is achieved on the month of September, 2017. The lowest OEE registered on August, 2017 which was 48 %. This is shown on figure 5.5. Data used for OEE calculation is attached on Appendix B3.

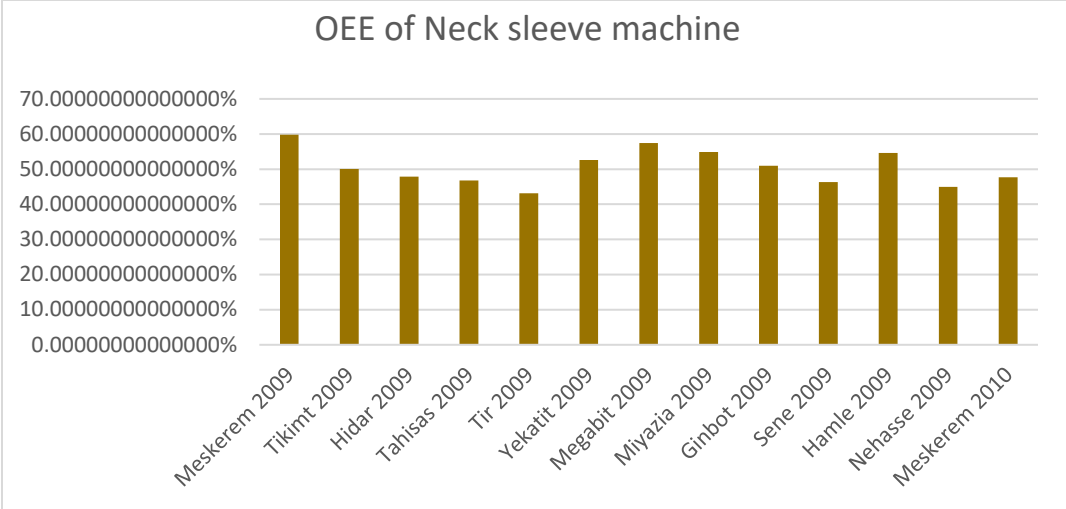


Figure 5.3: OEE of Neck sleeve machine

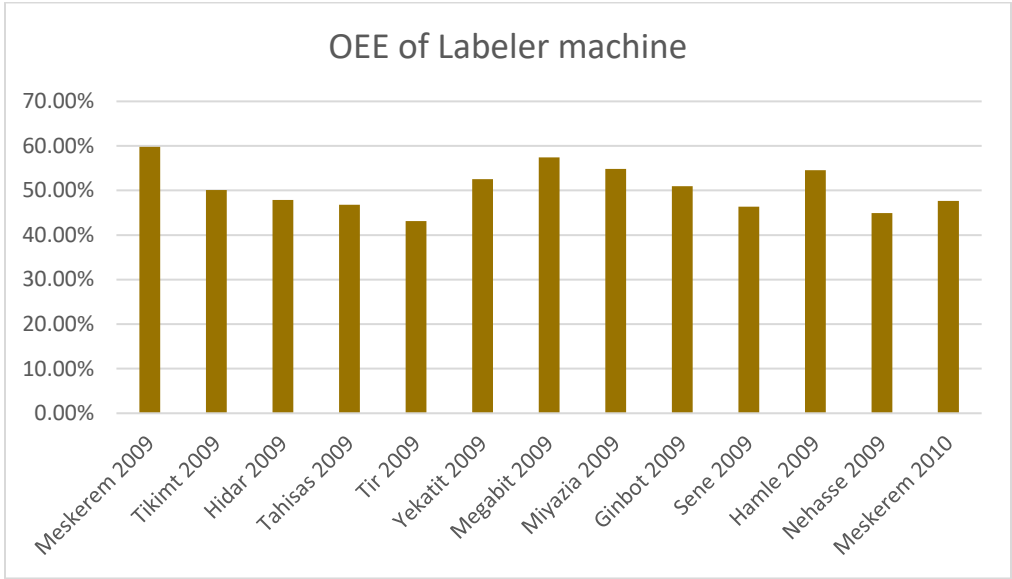


Figure 5.4: OEE of labeler machine

The highest OEE of packer machine was 65 % this is achieved on the month of September, 2017. The lowest OEE registered on August, 2017 which was 48 %. This is shown on figure 5.5.

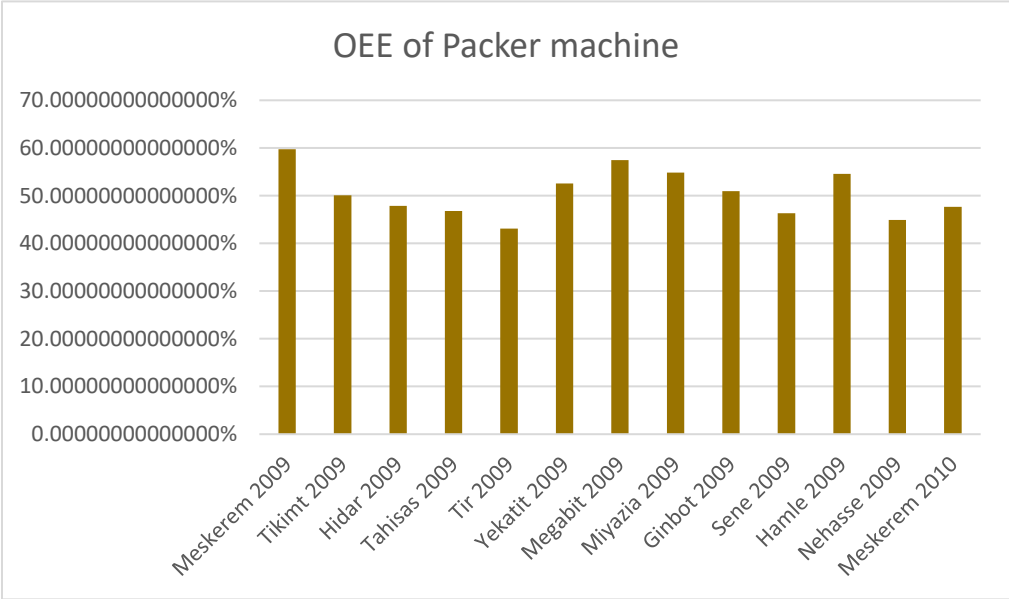


Figure 5.5: OEE of packer machine

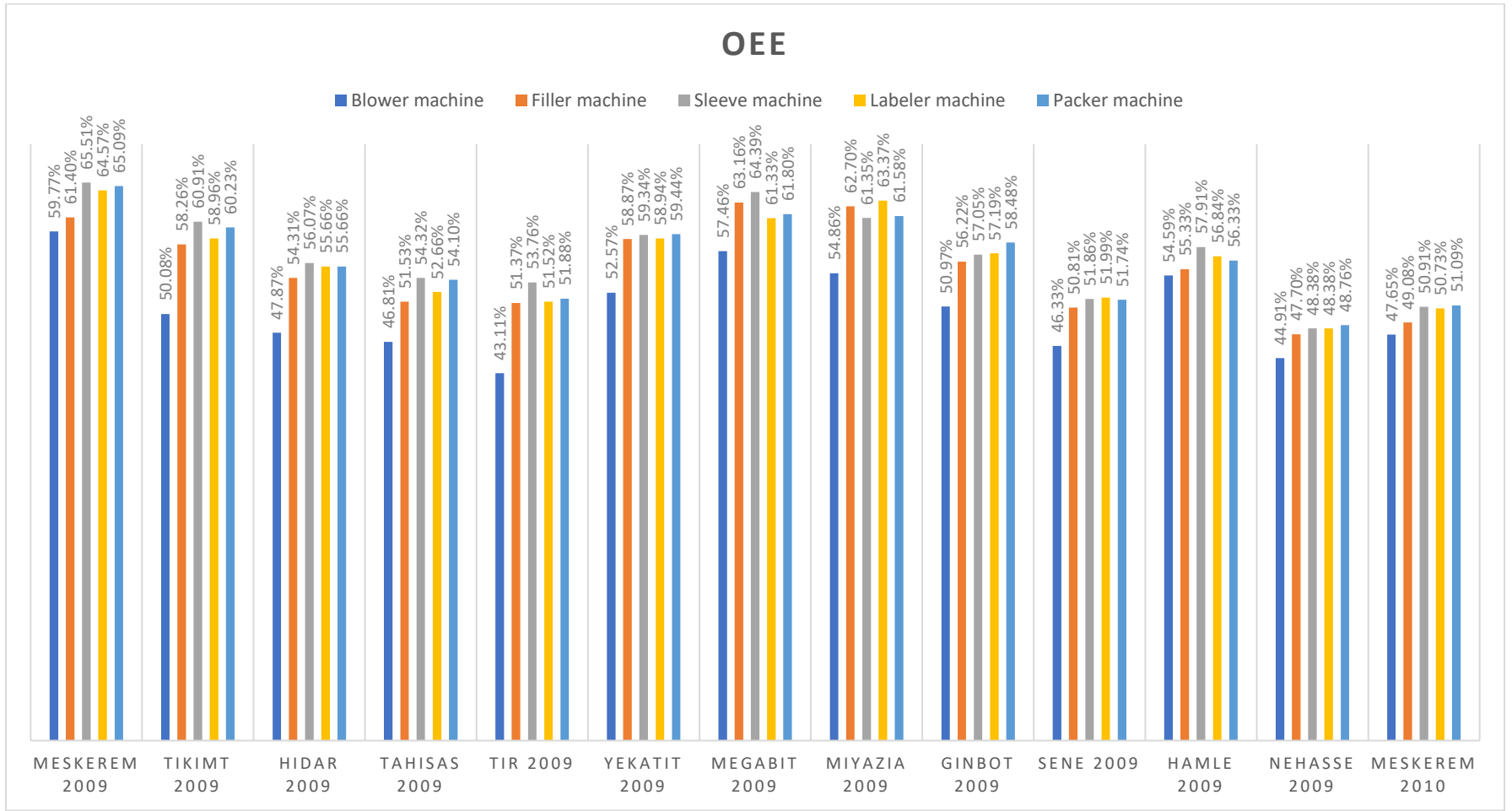


Figure 5.6: Summary of OEE trend

- 12.5% respondents do not maintain the equipment where as 87.5 % employees maintain equipment's. the support from their immediate superior during maintaining an equipment is rated on Figure 5.7.

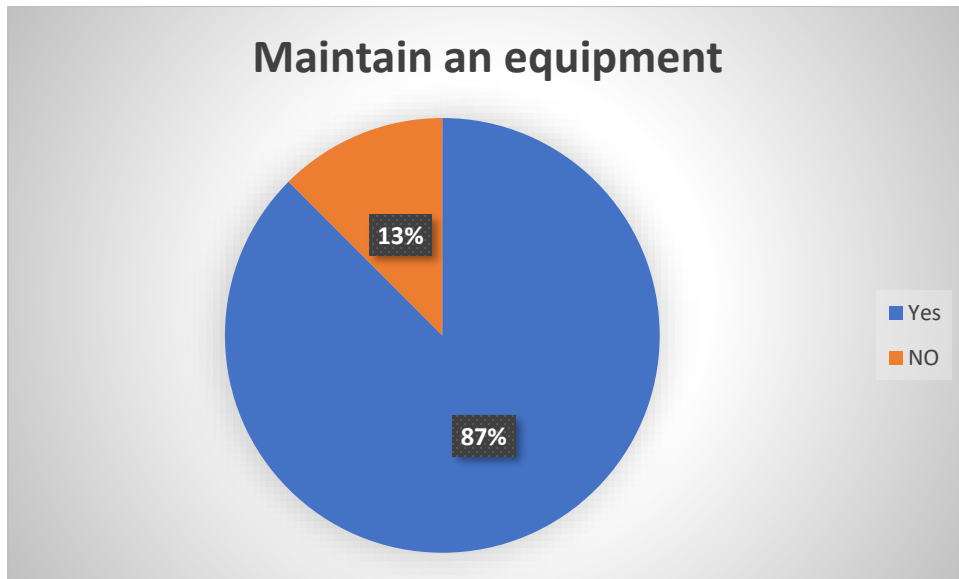


Figure 5.7: Direct participation of employees on machine maintenance

During machine maintenance 50% of the employees occasionally receive support from their immediate superiors'. Those 50 % respondents are working mainly on Blower machine and Filler machine.

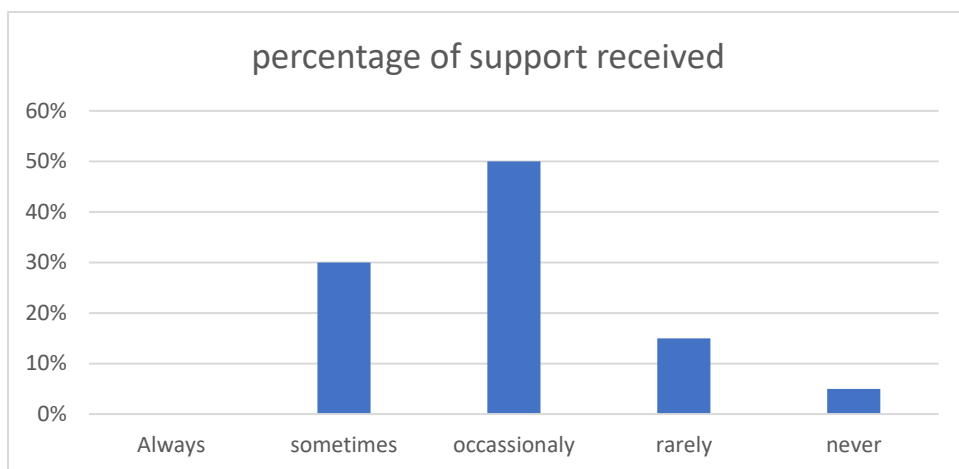


Figure 5.8: Support received during maintaining an equipment

Out of 87.5% of total respondents who maintain an equipment and all of them can maintain more than 5 different types of machine.

65 % respondents agreed that occasionally there is a good communication between production and technique department.

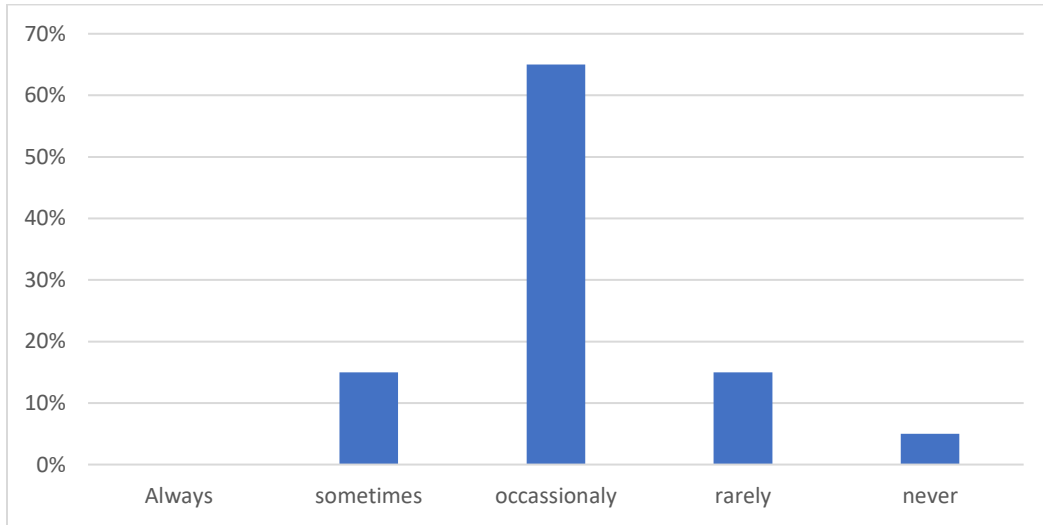


Figure 5.9: Good communication between production and technique department

On the questionnaire 100% respondents agree that maintenance of production equipment is a strategic factor for the company.

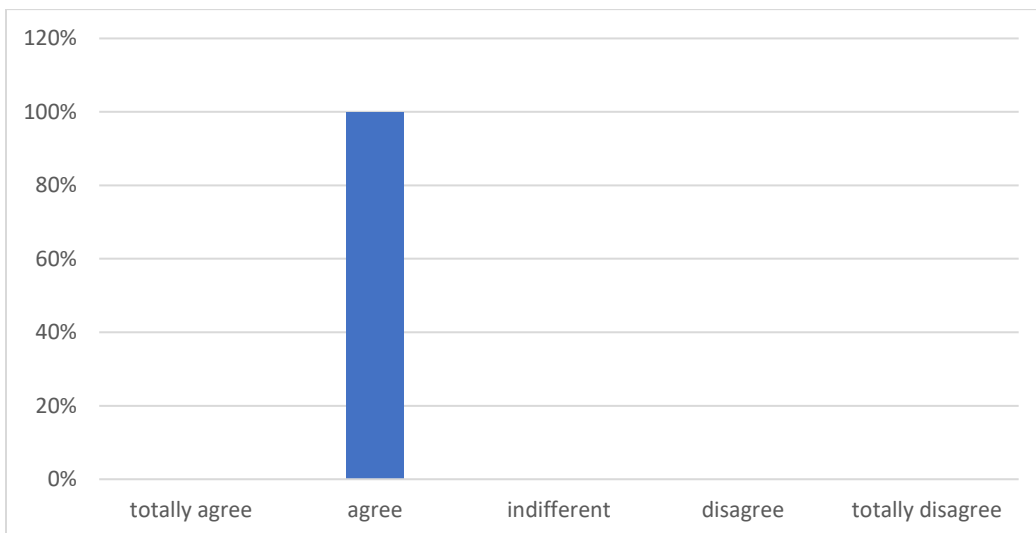


Figure 5.10: Maintenance of equipment as a strategic factor

100% respondents say the company has a maintenance strategy. Employees respond that the company has a maintenance strategy such as; preventive maintenance, corrective maintenance, breakdown maintenance and only few answers there are also predictive maintenance but they do not have equipment to predict rather they use their experiences such as abnormal noise, vibration, heat etc. as an indicator. Percentage of employees' response is shown on Figure 5.11.

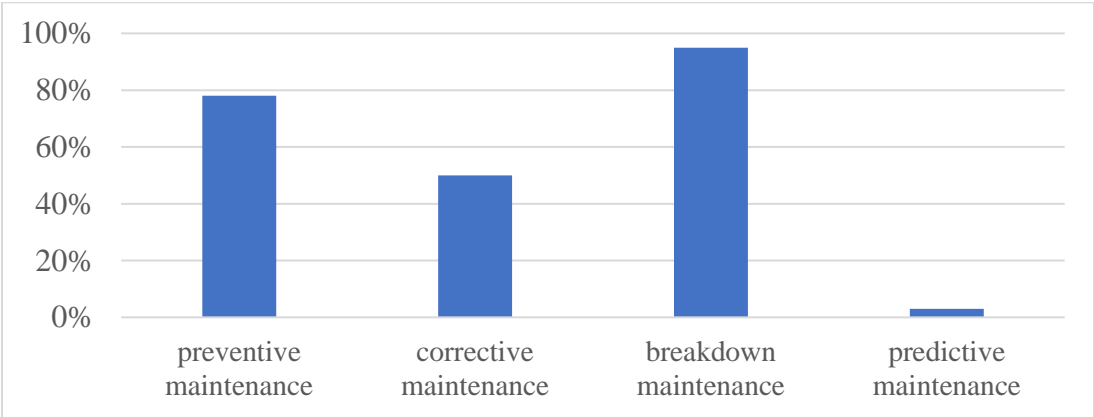


Figure 5.11: Followed maintenance strategies

83. 33% of the respondents said equipment's fails repeatedly. Mostly immediate response is given by technical team when an equipment fail, the response rate is described on figure 5.12.

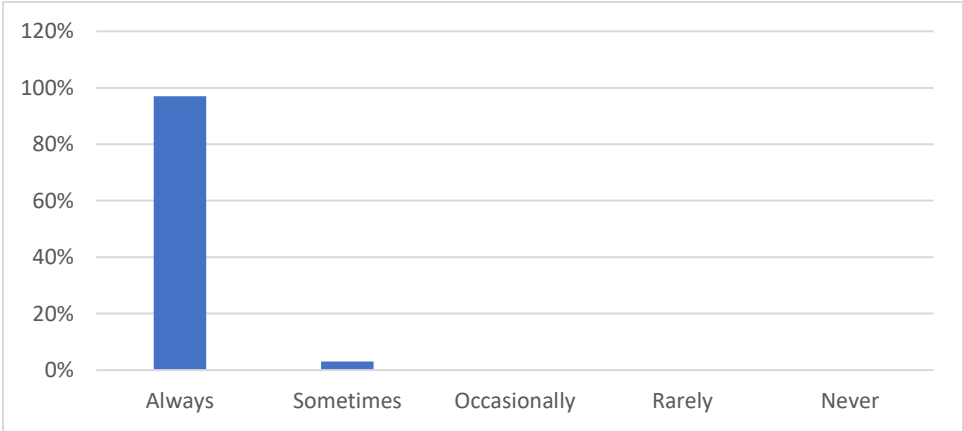


Figure 5.12: Quick response rate to repair an equipment

50 % of employees does not recognize failure before it happens. Only 20 % of respondents always recognize failure before it happened.

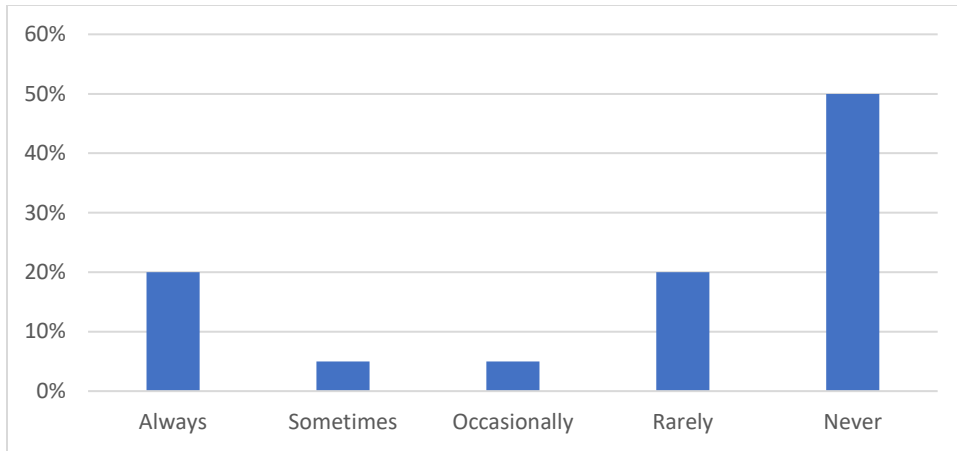


Figure 5.13: Tendency to recognize failure before it happens

The reasons for failure include

Lack of proper maintenance

- Improper machine handling
- Shortage of manpower
- Shortage of required spare parts
- Unavailability of required tools and equipment's
- Lack of skilled manpower
- Lack of training for technical team
- Lack of employee commitment

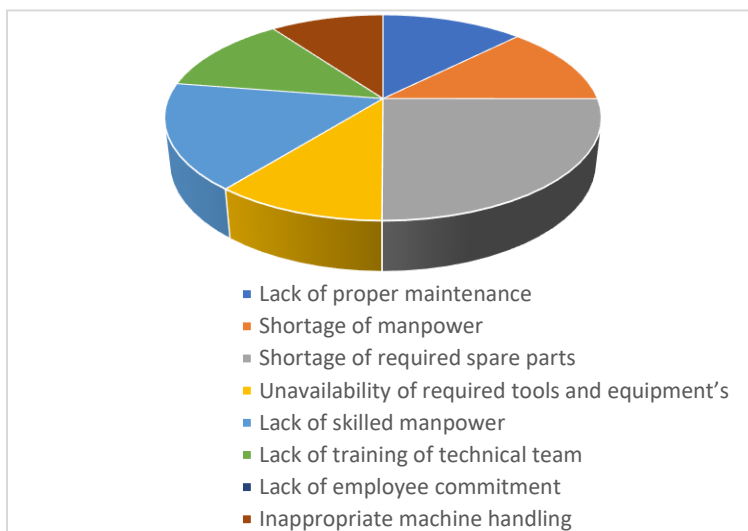


Figure 5.14: Causes of machine breakdown

Table 5.2: Maintenance strategies followed on different machines

| Maintenance Types | Blower Machine | Filler Machine | Neck Sleeve Machine | Labeler Machine | Date Coder | Packer Machine |
|------------------------|----------------|----------------|---------------------|-----------------|------------|----------------|
| Preventive Maintenance | √ | √ | √ | √ | √ | √ |
| Corrective Maintenance | | | √ | √ | √ | √ |
| Breakdown Maintenance | √ | √ | √ | √ | √ | √ |
| Predictive Maintenance | √ | | | | | |

Among different techniques to analyze failures; FME, cause and effect analysis, root cause analysis, PDCA and 5S selected by respondents

In addition to this 14% of respondents mentioned that they do not use any technique to analyze failure.

The company uses maintenance performance indicators such as

- Mean time between failure
- Mean time to repair
- Backlog
- Availability and
- Downtime

All respondents say there is a maintenance plan. 57.1% of the respondents say they have adequate maintenance procedure but the rest 42.9 % responds they do not have adequate maintenance procedures in place.

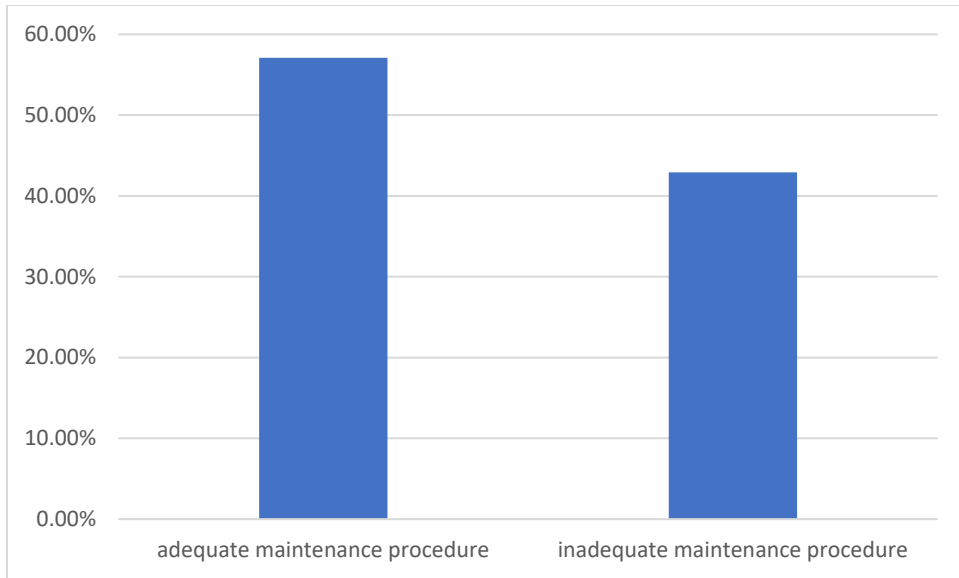


Figure 5.15: Maintenance procedure

Two third of the respondents agree that they do not have proper tools for maintenance and one third of them responds they have adequate tool for maintenance activities.

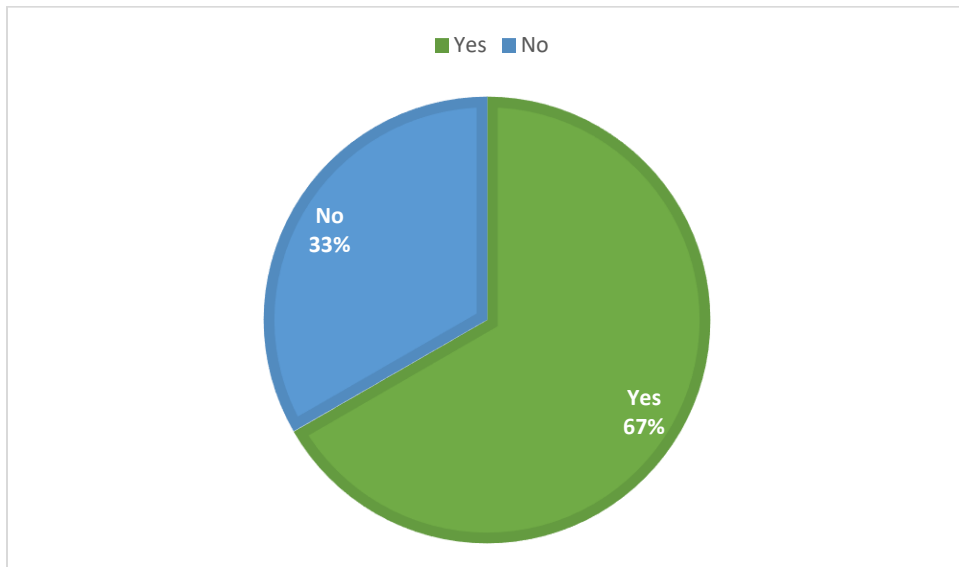


Figure 5.16: Availability of proper tool

Condition of available tools described on table 5.3.

Table 5.3: condition of tools

| Condition of tool | Quantity (in %) |
|-------------------|-----------------|
| New | 5.0% |
| Old | 75.0% |
| Like New | 10.0% |
| Broken | 10.0% |

100% employees responds that they are keeping their tools at suitable location.

The company has a frequency for maintenance activity on daily, weekly, monthly, semiannually and yearly basis.

The company uses;

- CMMS
- Spreadsheet
- Manual paper recording system to record maintenance related data's.

Though it is not updated, only Maintenance planner uses Microsoft NAV dynamics as CMMS other maintenance crews does not have access of the system.

14% of the respondents agree that there is training schedule for maintenance crew and the rest 86% of them says there is no training schedule for the team. 100% responds that training are not provided as per the schedule.

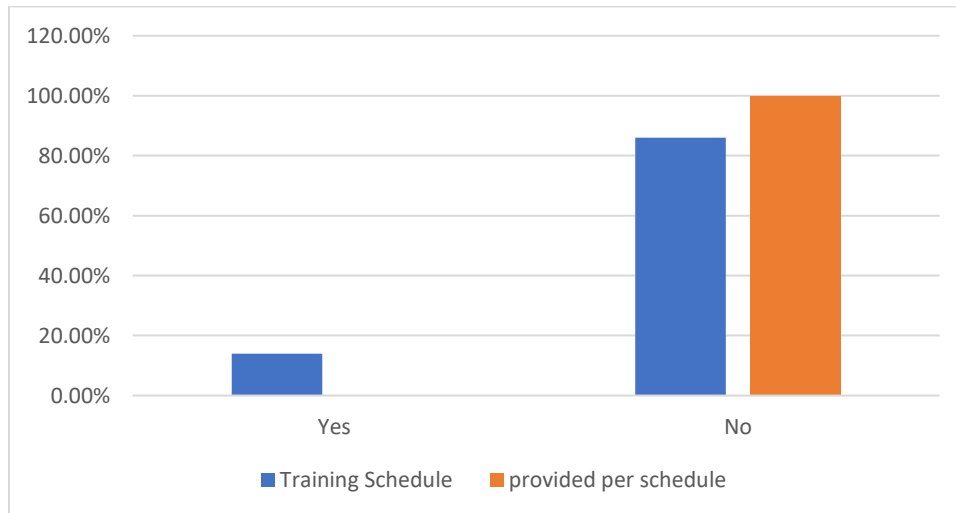


Figure 5.17: Training schedule and implementation

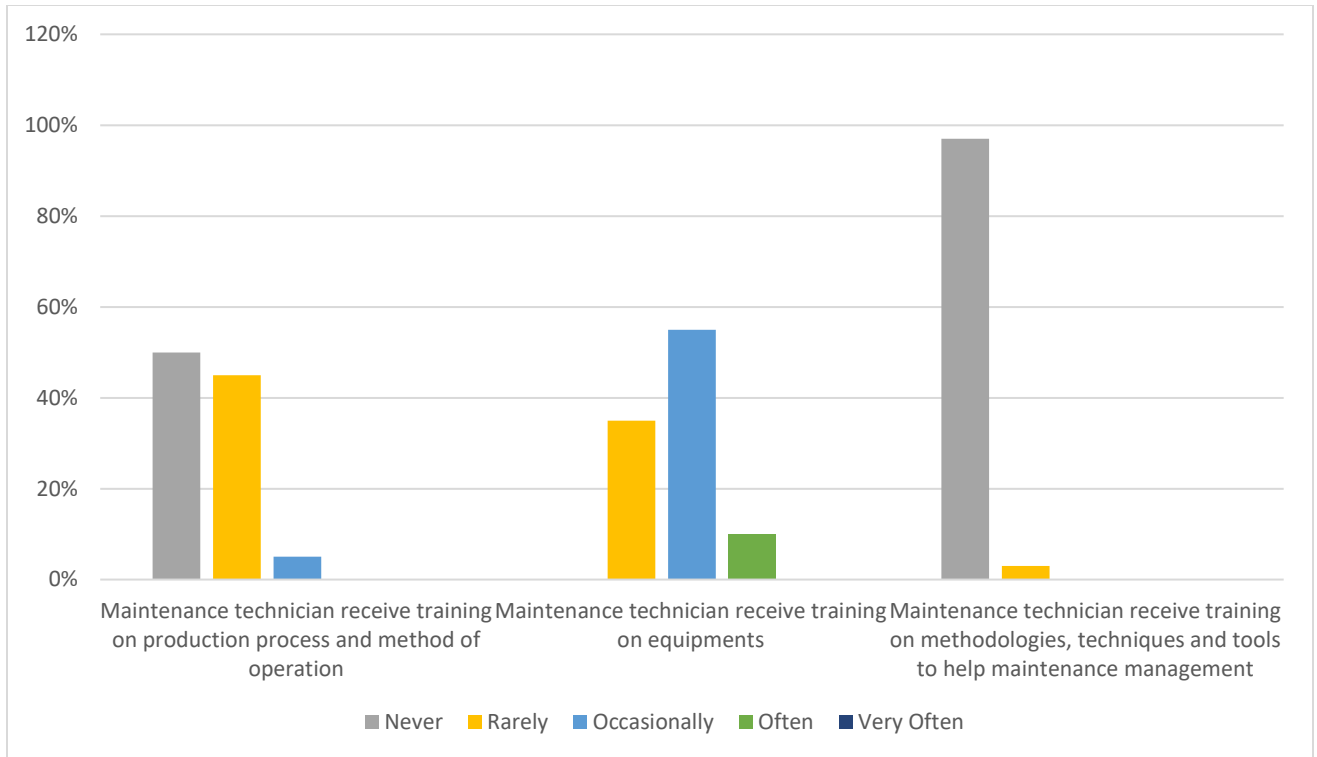


Figure 5.18: Training covering areas

A summary of total downtime percentages of 13 months' data summarized on figure 4.4

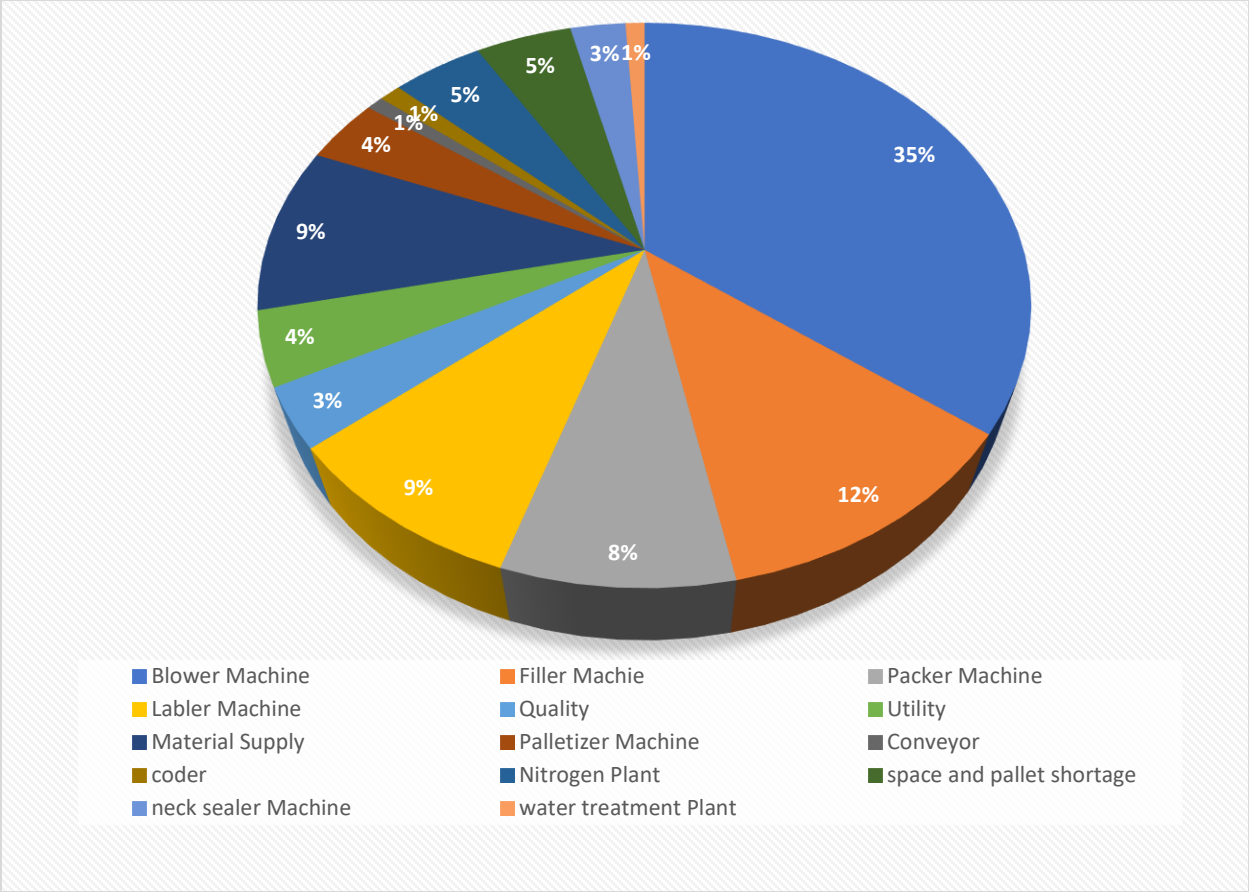


Figure 5.19: Total downtime summary

Filler machine breakdown and blower machine breakdown takes 48% of total breakdowns. The major breakdown parts are summarized on table.

Table 5.5: Blower and Filler machine

| Major Downtime | |
|---|--|
| Blower Machine | Filler Machine |
| <ul style="list-style-type: none"> ✓ Blower and filler sync. Problem ✓ cooling bar ✓ discharge ✓ heater ✓ infeed ✓ mold and ✓ mold bearing failure ✓ mold seal damage | <ul style="list-style-type: none"> ✓ Bottle transfer guide mechanical problem ✓ Cap releaser mechanical problem ✓ Capper guide bottle jamming ✓ Capper main motor problem ✓ Capper over & under torque ✓ Filler main motor failure ✓ filler pump & pneumatic valve shaft problem ✓ Filling temperature fluctuation |

| | |
|---|--|
| <ul style="list-style-type: none"> ✓ preform insert alarm and abnormal mold closing ✓ Servo Motor ✓ stretch rod ✓ transfer unit mechanical and electrical problem | <ul style="list-style-type: none"> ✓ Filling valve ✓ Homogenizer and UHT steam exchanger ✓ Pneumatic valve problem ✓ Rinser gripper ✓ Under filling and overfilling |
|---|--|

Observation

Tag and detag system started at some areas. But it lacks follow up, some tags are not readable at all because the ink is washed by water. There is no procedure for tag and detag system.

Bad maintenance culture observed in different culture. There is poor maintenance hygiene also.

5.2. Results and Discussion

World class practices shows that best practice of OEE is 85%. The smallest OEE value throughout the data is blower machine OEE. As shown on Figure 5.6 OEE trend of all machines almost the same. This is because of blower machine. Since the production nature is continuous/linear, the rest of the machines governed by blower machine capacity. Due to this reason, OEE of filler machine, neck sleeve machine, labeler machine and packer machine cannot show their real OEE value. Therefore, since the whole system is dependent on blower machine to analyze the system the researcher divides the system in two parts.

1. Blow molding: it consists only blow molding machine
2. Process: includes water treatment, filling and packing process.

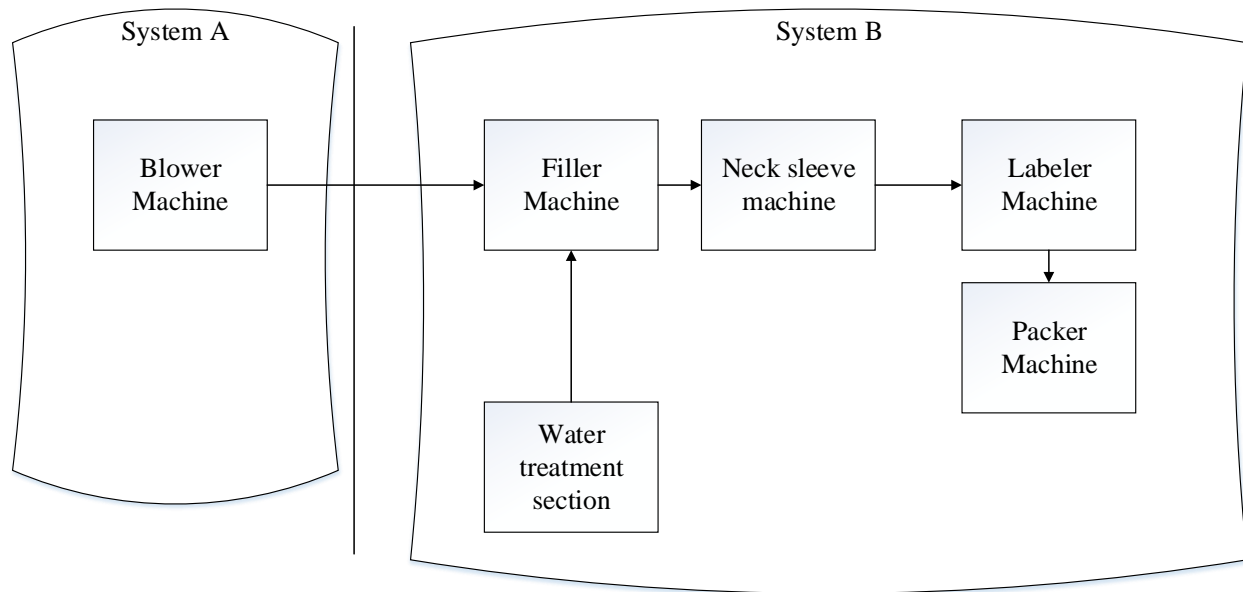


Figure 5.20: system classification

Most employees including operators can maintain different type of machines. This is a very good trend of the company that the employees have experience at hand.

The employees receive support from their immediate superiors when maintain a machine. The positive side of this is that while working together there is a benefit of sharing experiences, adding knowledge from senior staffs and employees can upgrade their knowledge and skill. On the other hand, if the support is given more frequently this could be an indication of incapability of the assigned employee on their specific job.

Technical staffs maintain different types of machines. The advantage of this is that during breakdown any technical staff that is near to the machine can start maintaining immediately. In contrary its disadvantage is that it is difficult to find a specialist on a specific machine that has detailed knowledge and ability to solve critical problems.

Communication between production department and supportive departments like the maintenance department is very crucial/ invaluable in a factory. Current status of the communication among these two departments is average.

In today's competitive market, equipment maintenance has to be seen as a strategic factor for the success of a company (Salonen, 2009). In the same way respondents said this is also true at Asku plc. But the fact on the ground is the reverse because equipment's are under frequent breakdown.

Previous studies showed that mixed maintenance strategy is possible in one company (Naughton and Tiernan, 2012). Similarly, the case company follows preventive, corrective, breakdown and predictive maintenance strategies with limitation, especially for predictive maintenance. This is because there are no adequate devices to predict the machine status. Employees are using more of traditional ways of prediction for example noise, vibration. This will not prevent machine failures since it will be depending on only the skill of the employee.

Based on the data, even though there are a preventive and corrective maintenance strategies, mostly breakdown maintenance occurs. This shows there is a problem with preventive maintenance schedule and or checklist itself. Because, if the preventive maintenance was successful breakdown would not happen frequently.

There is a high rate of immediate response when an equipment fails. This will reduce meantime to repair of an equipment. In other words, it will increase availability of an equipment.

Operators and mechanics damage machines by not knowing the exact root cause of the problem. Only solving observed problem, would eventually cause another machine failure.

Even though respondents choose FMEA, cause and effect analysis, root cause analysis, PDCA, and 5S to analyze failure, there is no documented evidence that these techniques are applied. As per the maintenance and engineering department manager there are few RCA conducted by him but it was not communicated to the team. Therefore, there is a chance that the same problem might happen again due to communication problem of the department.

There is no standard work flow system previous studies revealed that work flow system is the information system for the maintenance organization. Without the dedication to record all of the maintenance activities on a work order, the organization does not have the data to perform any meaningful analysis on its policies and practices, or more importantly on the equipment it is responsible for maintaining (Wireman, 2005). There is documented maintenance procedures and plans, it is not communicated down to the team due to these reason, technical staffs are not aware. Therefore, written documents are useless

As per the KPI document review listed KPIs are sound. But there is no evidence that those performance indicators are evaluated in accurate way since there are no records even formats that shows performance indicators are performed.

Training provided to the technique team regarding machine operation and maintenance is very inadequate. Due to this, performed maintenance during breakdown and planned maintenance is not effective. Also operators and mechanics mishandle machines and maintenance tools get damaged due to inappropriate usage.

Culture of record keeping after maintenance is very poor. This leads to unavailability of machine history information which is difficult to plan maintenance activity for machines. Even though the ERP system that the company has maintenance module, current

Generally, there is an indication that somehow the case company takes maintenance activities as an important function but there are limitations on

- Focus on proactive maintenance strategies.
- Record keeping and documentation on maintenance activities and history.
- Traditional workflow.
- Knowledge and skill gap on how to maintain a machine, how to use maintenance tools and techniques/ Adequate training to equip operators with the skills and knowledge they need to perform their maintenance operations.
- Over all, unavailability of holistic and standardized maintenance strategy frame work across the board the factory follows.

The reason behind the observed gaps is top management took maintenance as a necessary evil. This ideology controlled developed countries manufacturing companies on in 20th century but in recent years, industry managers have been gradually moving to the idea that maintenance can be a profit generating function rather than merely a cost center (Kym et al., 2015).

Chapter 6: Conceptual Framework of Maintenance Management

6.1. Introduction.

Per the results of the study the company has gaps on proactive maintenance, knowledge and skill on maintenance management and to perform maintenance activities, record keeping and documentation on maintenance activities and history. Over all, unavailability of holistic and standardized maintenance strategy frame work across the board the factory follows.

Therefore, developed model at section 6.2 addresses above listed gaps.

6.2. Conceptual Framework

Developed conceptual framework for case company is based on the identified gap during data analysis and discussion.

Set maintenance strategy: this will be set directly from company business objective. Identifying maintenance strategy is very important to know the main role of maintenance department in the organization.

The objective includes:

- To insure the safe keeping of machineries and equipment.
- To increase that machine availability by 10 % in 2019.
- To improve the skill and knowledge of the maintenance crew.
- To insure availability of spare parts and lubricants.

Identify existing problem area: OEE used to identify bottle neck process for the whole process. Blower machine is a bottleneck machine to the system. This is already indicated on Figure 5.1.

Identify critical components of the bottle neck. Failure mode and effect analysis performed to identify critical components of blower machine. FMEA of blower machine conducted with the help of blower machine expert and quality control and assurance team.

Table 6.1: Blow molding machine failure mode and effect analysis

| Element | Failure description | Severity | Cause of failure | occurrence | Detection Method | Detectability | RPN |
|---------|--|----------|---|------------|---|---------------|-----|
| | Selector might not transfer the preform in right position | 5 | Wear due to friction | 2 | Preform will fall on the ground | 2 | |
| | Up and down pneumatic cylinder cannot move up and down properly | 6 | Wear of cylinder seal and O-ring seal | 6 | Cylinder will stop in a wrong position and it will not actuate | 2 | |
| | Forward backward cylinder cannot move forward backward movement properly | 7 | Air adjustment problem, flexible joint might get wear due to age | 6 | Cylinder will stop in a wrong position and it will not actuate | 4 | |
| | Forward and backward cylinder cannot move forward backward movement properly | 6 | Position/ adjustment, loose bolt causes off center | 6 | When putting preform in to spindle the center of spindle and preform will not align | 4 | |
| | Preforms will not fit to the spindle properly | 6 | Robot handle finger wear due to friction | 5 | Preforms position at spindle is not vertical | 2 | |
| | Robot handle Broken | 6 | It has a high movement due to this it get loose and during over tight the thread will get damage | 4 | Preforms position at spindle is not vertical | 2 | |
| | Up and down pneumatic cylinder | 6 | Centering problem of locator with preform, due to different sizes of preform the rubber seal will get damaged | 4 | Preform neck will damage, it is detected by necked eye | 2 | |
| | Rotator cylinder | 6 | Loose or over tight of lock nut, damaged rack and pinion gear | 8 | Locator will stuck at any point, it causes noise | 7 | |
| | Sensor malfunction | 5 | Sensor location, electrical short | 4 | Machine shutdown | 4 | |

| | | | | | | | |
|----------------|---|---|---|---|---|---|--|
| stretch rod | Bottle will not transfer to the next position | 8 | Insufficient space between stretch rod and spindle | 7 | Transfer will not get forward the machine will get down | 2 | |
| | Sensor malfunction | 5 | Stretch rod sensor alignment | 8 | Machine will shut down | 2 | |
| | Stretch rod pneumatic cylinder malfunction | 7 | Wear of stretch rod pneumatic cylinder seal and O-ring seal | 5 | Pneumatic cylinder will not move/ it will stuck | 2 | |
| molding system | Open and close hydraulic cylinder internal seal gets damage | 4 | Inside the cylinder there is a rubber seal and it might get damage due to lack of oil | 3 | Mold will no open and close, there will be loud noise | 4 | |
| | Removal of allen shaft | 4 | Improper cylinder and toggle adjustment | 3 | Bottle neck gets deformed shape | 3 | |
| | Stretch rod pneumatic cylinder malfunction | 5 | Wear of bottom mold pneumatic cylinder seal and O-ring seal | 2 | | 2 | |
| Blow system | Shortage or excess of high pressure, air leakage | 3 | High pressure air gets low | 6 | Output is foggy or deformed bottles | 2 | |
| | | 3 | Sensor synchronization problem | 2 | Machine will stop | 4 | |
| cooling system | Cooling bar blockage | 7 | Due to dirt or presence of algae, improper cleaning | 8 | Deformed bottles produced, | 2 | |
| | Misplaced cooling bars | 8 | During heater maintenance the position of the cooling bar might changed | 8 | Deformed bottles produced, | 2 | |
| sealing part | Air leakage | 4 | Rubber seal damaged. | 7 | There will be loud noise, shape of the bottle will be different from desired shape. | 2 | |
| Air system | Compressed air shortage | 3 | Low compressor output, environmental temperature, leakage on air line | 4 | Bottles will have deformed shapes, machine will stop | 2 | |

The result of FMEA shows that infeed and discharge, stretch rod and cooling system are the critical components of bottle neck machine, which is blower machine.

Select maintenance strategy: tacit and explicit knowledge used due to incomplete data (Waeyenberg and Pintelon, 2009). Based on the discussion with technical experts' preventive maintenance is selected for blower machine with the rationale of its dominance on the performance of the machine. In addition to that autonomous maintenance is best for the company because of available manpower in the department and autonomous maintenance preferred to conduct preventive maintenance. Because autonomous maintenance empowers operators to minimize response time and perform productive maintenance this aims to improve the maintenance skills and knowledge among shop floor operators. It also improves machine availability through better utilization of maintenance and production resource. In addition, this also free the maintenance staff to specialize on specific machines to perform more and more on planned maintenance.

Workflow system: is the information system for the maintenance organization very important for the success of the job (Wireman, 2005). Since there is no standard work flow, new workflow proposed on figure 6.1. This has to be followed by maintenance planner.

Without the dedication to record all of the maintenance activities on a work order, the organization does not have the data to perform any meaningful analysis on its policies and practices, or more importantly on the equipment it is responsible for maintaining. In addition, without a work flow system, it is impossible to plan and schedule maintenance activities.

Work orders raised by other department employee will fill work order request form and approve by his/her department manager and submit to maintenance planner. If work orders raised by technical team staffs, he/she fill tag and put on that specific area. Therefore, planner will organize work orders from work order request format and tags. Based on the dead line and urgency works will generate prepare spare parts, allocate manpower and required time to complete the job. Next work orders released to executors, during execution maintenance planners has to follow the progress and quality of work. After completion he/she validate or confirm that the maintenance activity is successful. This can measure by reworks and or number of defects. The last stage is recording keeping. It helps to build machine histories, measuring performance, helps for decision making purpose also.

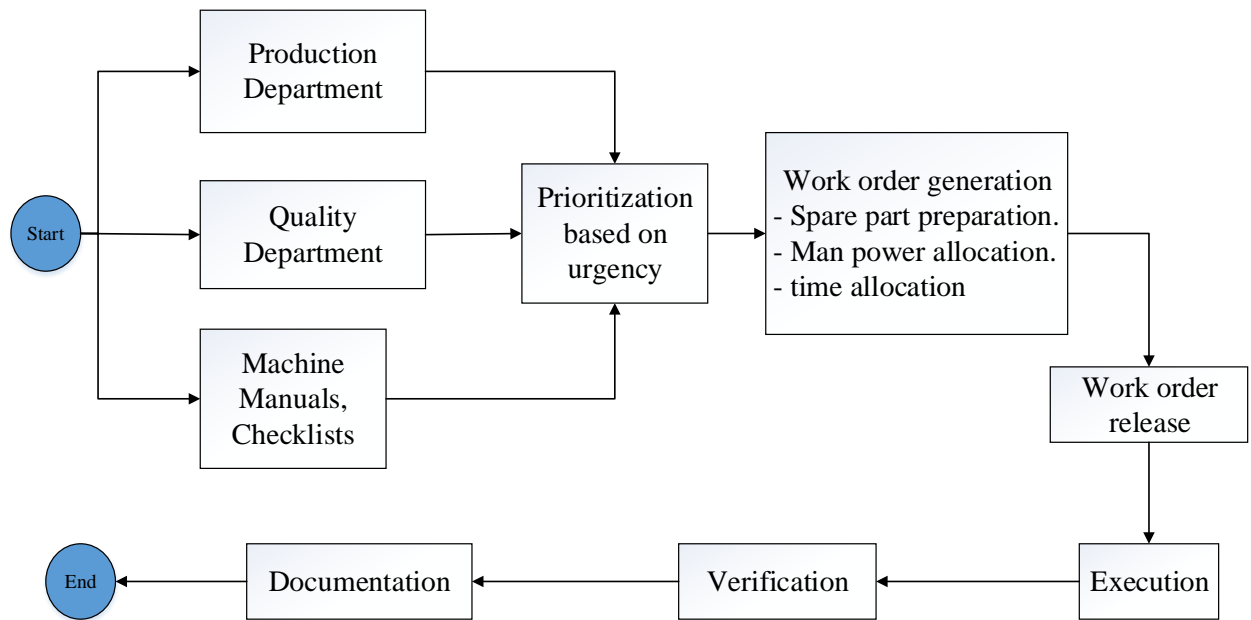


Figure 6.1: proposed workflow

Computerized maintenance management system: is faster and easier to collect data and then manipulate that data into a meaningful report format. Every information of failures, machine breakdowns, time taken to,

The company has Microsoft NAV dynamics ERP system, on maintenance module of this system work orders can be processed.

Set key performance indicators: selected performance indicators listed below. The indicators derived from maintenance objective

- Unplanned technical downtimes.
- Number of running and none running inspections
- Percentage of maintenance work order completed.
- Number of practical training given for succession plan
- Percentage of maintenance work orders requiring rework

| MEASUREMENTS(KPI) | Measurement | Weight/ 100% | Targets/ Baseline |
|---|---|-----------------|----------------------|
| Objective KPI (100%) | | | |
| Unplanned technical downtime | In % | 30% | >=5 % |
| PM conducted according to the checklist / PM schedule Compliance | Coverage of the checklist in numbers or % | 10% | 100% |
| Inspection conducted/ Running and Non-running// | Number of validated TAGs | 10% | Min 45 |
| | Number of DETAGs | 10% | Min 30 |
| Percentage of maintenance work orders completed within the specified period | In % | 20% | 85% |
| Percentage of maintenance work orders requiring rework | In % | 10% | < Less than 3%. |
| Number of practical training given for succession plan | In % | 10% | 100% |

Figure 6.2: proposed KPI

Continuous improvement: after measuring the performance, the result will lead for potentially improved areas such as setting objective, identifying most important system and its critical component, maintenance strategy, work flow system, CMMS or performance indicators. Therefore, by following this loop there is always an improvement on the maintenance management system. For example, When the business objectives are changed, the measurement system should be changed accordingly. Failing this, the measurement system cannot be used to control the strategically important success factors.

Proposed framework will benefit the company by placing a system to increasing machine performance, reducing down time and by helping to produce consistent quality products.

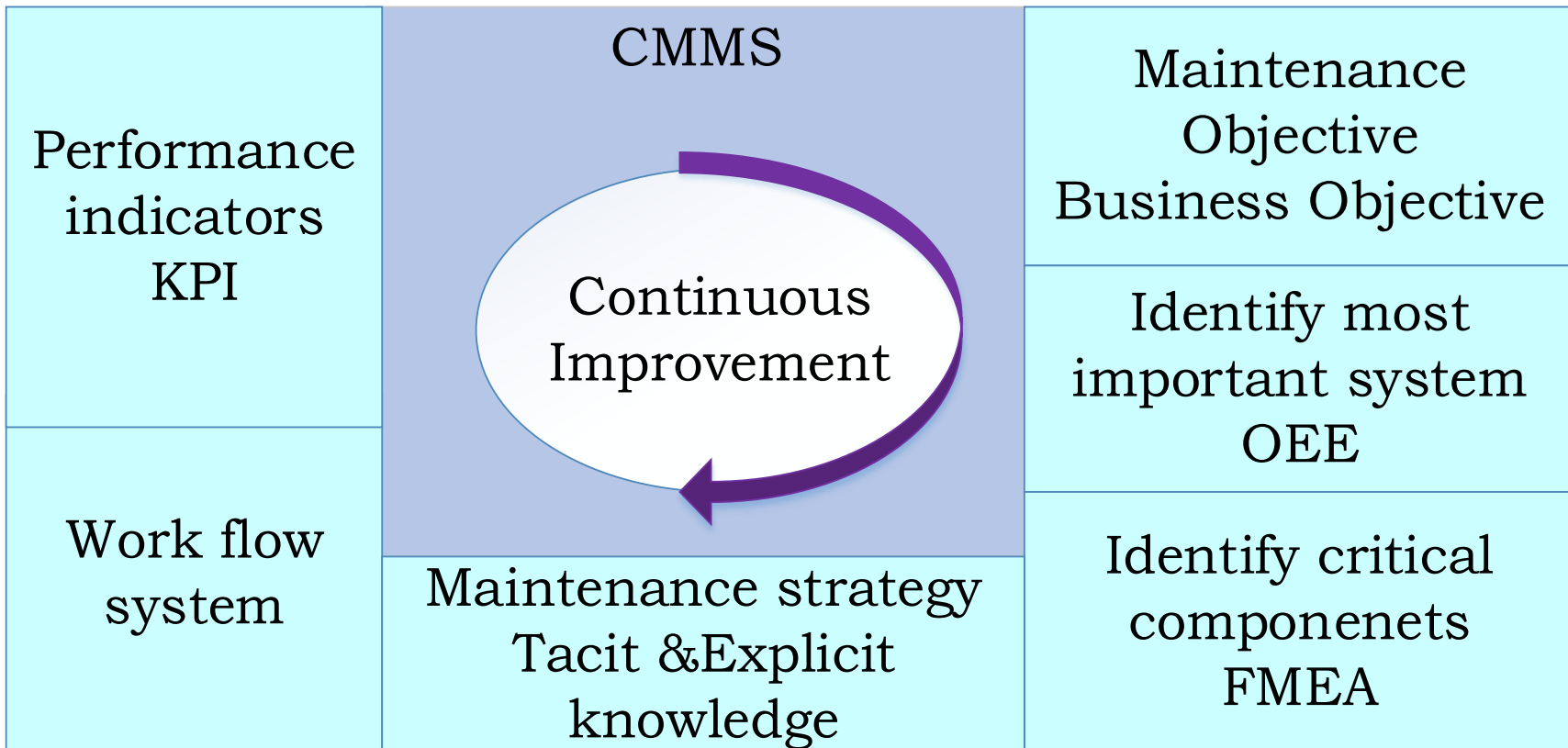


Figure 6.2: Conceptual framework of maintenance management

6.3 Implementation procedure

A certain step needs to be followed during implementation.

1. Briefing and convincing top management the about the importance of maintenance function for the company success.
2. Form a team from different background.
3. Provide a training for the team with regard to:
 - What is the business objective of the company?
 - What the major contributor for the company success?
 - What are the objective of maintenance and engineering department?
 - What are the types of maintenance strategies, with their advantage and limitation respectively?
 - Tools and techniques that can be used for failure analysis
4. Selected team will start implementing maintenance management framework. Sequence will be:
 - Set maintenance strategy
 - Identify systems by using OEE
 - Identify critical components by doing FMEA
 - Select maintenance strategies to be followed
 - In place workflow system
 - Set KPI for each position at maintenance and engineering department.
 - Prepare information recording formats for the performance indicators. This will make KPI evaluation accurate.
 - Based on the performance improve the system continually.

6.4 Validation

Because of time constraint validation of the frameworks done by discussion in a meeting with the presence of plant manager, maintenance and engineering manager and technical experts.

During discussion, raised points include relevance of the framework, feasibility of framework, in what area may the framework has to be improved.

Per the discussion, framework is relevant and feasible because it addresses practical problems. It requires minor modification on workflow, checklist is recommended to incorporate on the workflow. Because Checklists can be also source of work order generation. In addition to this exhaustive training of all maintenance and engineering department staffs and machine operators required to implement maintenance management system effectively and efficiently.

Chapter 7: Conclusion and Recommendation

7.1 Conclusion

In developing countries, taking maintenance as a core business function is at an infant stage. This conclusion is taken because, there is limited academic study and industrial application in Africa. The situation in Ethiopia is similar with other developing countries, maintenance is taken as a cost center and the number of studies is very limited. In this study food and beverage industry is selected as a case.

Literatures reviewed intensively on maintenance strategies, maintenance management models, performance measurements, for this research 9 maintenance frameworks reviewed. Both empirical and theoretical gaps identified and incorporated on developed framework. Based on the study on the case company, blower machine is a bottle neck to the system. The company has limitation of focus on proactive maintenance strategies, record keeping and documentation on maintenance activities and history, knowledge and skill gap on how to maintain a machine, how to use maintenance tools and techniques and over all, unavailability of holistic and standardized maintenance strategy frame work across the board the case company follows.

The framework has 8 building blocks. It starts by setting maintenance objectives. The objective is derived from business objective of the company. The second building block is determining the system. OEE used to determine the system. per the result two sub systems identified. The first system is a bottle neck to the whole system. Therefore, by using FMEA major failure modes identified. The next building block is choosing maintenance strategy. This is done by using tacit and explicit knowledge of the experts. The method is chosen because of data unavailability. Fifth building block is a proposing a work flow system in order to have uniform or standard workflow

for maintenance activities. The sixth block is identifying performance indicators as per maintenance objective. The seventh building block is continuous improvement, after measuring the performance improvement areas will be revealed. To address improvement areas, the cycle will continue. All these seven building blocks are integrated by computerized maintenance management system. This CMMS will have necessary information to measure the performance and generating accurate and relevant reports in no time. It is also important to develop machine history which is relevant to prepare maintenance checklists, maintenance plan and other decision making. Building block five and seven addressed identified theoretical gaps.

Validation of the framework done by discussion in a meeting with technical team. Valid feedback given on work flow process and based on the feedback workflow process amended.

7.2 Recommendation

Based on the result of the above study the case company recommended to take below listed measures in order to become effective and efficient on maintenance activities, this also maximize production output.

- Implement the maintenance framework in the company to enhance down time
- Replace blower machine with higher capacity.
- Increase number NAV Dynamics users of technical teams in order to have better communication inside the department in order to monitor pending jobs, spare part management, save time to generate sound and accurate relevant reports.

- Update or customize the CMMS software to generate current missing information such as maintenance reports on daily failure, backlogs, rework, spare part stock, and other relevant information.
- Upgrade maintenance staff's knowledge on key performance indicators by exercising at lower level in terms of reports.

Reference

1. A. Parida and U. Kumar, (2006) "Maintenance performance measurement (MPM): issues and challenges", *Journal of Quality in Maintenance Engineering*, vol. 12, Issue no. 3, pp. 239–251.
2. Aditya Parida, Uday Kumar, Diego Galar, Christer Stenström, (2015) "Performance measurement and management for maintenance: a literature review", *Journal of Quality in Maintenance Engineering*, Vol. 21 Issue: 1, pp.2-33
3. Adolfo Crespo Márquez, (2007) "The Maintenance Management: Framework Models and Methods for Complex Systems Maintenance", Springer-Verlag London Limited, UK
4. A. Crespo Márquez, P. Moreu de León, J.F. Gómez Fernández, C. Parra Márquez, M. López Campos, (2009) "The maintenance management framework: A practical view to maintenance management", *Journal of Quality in Maintenance Engineering*, Vol. 15 Issue: 2, pp.167-178.
5. Ahuja, I. and Khamba, J. (2007), "An evaluation of TPM implementation initiatives in an Indian manufacturing enterprise", *Journal of Quality in Maintenance Engineering*, Vol. 13 No. 4, pp. 338-352.
6. Al-Najjar, B. (2008). "Maintenance from Different Perspectives: Total Quality Maintenance (TQMMain) for a Comprehensive Asset Maintenance", In *ICOMS Conference Proceedings* (p. 37/1-8). Asset Management Council, Surrey Hills, Australia.
7. Alsyouf, I. (2007) "The role of maintenance in improving companies' productivity and profitability", *International Journal of Production Economics*, vol. 105, no 1, pp. 70-78.
8. AMCP 706-132,(1975). "Engineering Design Handbook: Maintenance Engineering Techniques", Department of Army, Washington, D.C.,
9. American Society for Quality Control Statistics Division, (1983) "Glossary and tables for statistical quality control", 2nd edn. ASQC Quality Press, Milwaukee.
10. Amik Garg, S.G. Deshmukh, (2006),"Maintenance management: literature review and directions", *Journal of Quality in Maintenance Engineering*, Vol. 12 Iss: 3 pp. 205 – 238
11. Arunraj, N.S. & Maiti, J., (2007). "*Risk-based maintenance—Techniques and applications*", *Journal of Hazardous Materials*, 142(3), pp.653–661.
12. Ashok Prajapati, James Bechtel, Subramaniam Ganesan, (2012) "Condition based maintenance: a survey", *Journal of Quality in Maintenance Engineering*, Vol. 18 Issue: 4, pp.384-400
13. Brah, S.A. and Chong, W.K. (2004), "Relationship between total maintenance and performance", *International Journal of Production Research*, Vol. 42 No. 12, pp. 2383-2401.
14. B.S Dhillon, (2001) *Engineering maintenance- a modern approach*,CRC press, Florida, USA.
15. David Sherwin, (2000) "A review of overall models for maintenance management", *Journal of Quality in Maintenance Engineering*, Vol. 6 Issue: 3, pp.138-164,

16. Dhillon B.S.,(1987), “Engineering Management”, Technomic publishing Co., Lancaster, Pennsylvania, 1987.
17. Dzivhu Mungani and Krige. Visser, (2013) “Maintenance approaches for different production methods”, South African Journal of Industrial Engineering Volume 24, Issue no 3, pp 1-13
18. ERHQ-0004, Maintenance Managers Guide, Energy Research and Administration, Washington, D.C. 1976.
19. European Standard, (2010.) EN 13306:2010 English version, UK.
20. M. Faccio, A. Persona, F. Sgarbossan and G. Zanin (2014) “ industrial maintenance policy development: a quantitative framework”, journal of production economics volume 147, pp 85 – 93.
21. Haarman, M and Delahay, G. (2004), Value Driven Maintenance – New Faith in Maintenance”, Mainnovation, Dordrecht.
22. Hesham Alzaben (2015), “Development of a maintenance management framework to facilitate the delivery of healthcare provisions in The Kingdom of Saudi Arabia”, Nottingham Trent University, School of Science and Technology, PhD Dissertation, UK.
23. ISO 22000:2005 food safety management system manual
24. J.M. Simões, C.F. Gomes, M.M. Yasin, (2011) "A literature review of maintenance performance measurement: A conceptual framework and directions for future research", Journal of Quality in Maintenance Engineering, Vol. 17 Iss: 2, pp.116 – 137.
25. Jong-Ho Shina, Hong-BaeJun (2015) “On condition based maintenance policy”, Journal of Computational Design and Engineering, Volume 2, issue 2, pp 119 – 127.
26. Kathleen E. McKone, Roger G. Schroeder, Kristy O. Cua (1999)” Total Productive Maintenance: A Contextual View” Journal of Operations Management, Vol. 17, No. 2, p. 123-144.
27. Kishan Bagadia, (2006) “Computerized maintenance management system made easy: how to evaluate, select and manage CMMS”, McGraw-Hill, USA.
28. Kobbacy k.a.h., and Murthy D.N.P (2008) “Complex system maintenance handbook” Springerlink, USA.
29. Kym Fraser, Hans-henrik Hvolby and Tzu-Liang(Bill) Tseng (2015) Maintenance Management Models: a study of the published literature to identify empirical evidence. International Journal of Quality and Reliability Management, vol. 32, no. 6, pp. 635 – 664.
30. Mahesh Sharma and Alok Khatri (2015) “Total Quality Maintenance & Trouble Shooting: A Case Study”, International Journal of Emerging Technology and Advanced, Volume 5, Issue 3,pp 102 – 110.
31. Maletic, D., Maletic, M., Al-Najjar, B. & Gomiscek, B. (2014), “The role of maintenance in improving company's competitiveness and profitability: a case study in a textile company”, Journal of Manufacturing Technology Management, vol. 25, no. 4, pp. 441-456.
32. Marcelo A. de Oliveira, Isabel S. Lopes, Member IAENG, and Danielle L. Figueiredo, (2014) “Maintenance Management Practices of Companies of the Industrial Pole of Manau, WCECS 2014, San Francisco, USA.
33. Melesse Workneh Wakjiraa, Ajit Pal Singhσ, (2012) “Total Productive Maintenance: A Case Study in Manufacturing Industry”, Global Journal of researches in engineering Industrial engineering Volume 12 Issue 1.

34. Michael Daragh Naughton, Peter Tiernan, (2012) "Individualising maintenance management: a proposed framework and case study", *Journal of Quality in Maintenance Engineering*, Vol. 18 Issue: 3, pp.267-281,
35. Mohamed Ben-Daya, Salih O. Duffuaa Abdul Raouf, Jezdimir Knezevic and Daoud Ait-Kadi (2009) "Handbook of Maintenance Management and Engineering" Springer, London, UK.
36. Obamwonyi Martyn Enofe and Gregory Aimienrovbiy, (2010) "Maintenance impact on productin profitability", Linnaeus university, School of Engineering, Department of Terotechnology, May, 2010.
37. Omdahl TP, ed. (1988) "Reliability, availability, and maintainability dictionary", ASQC Quality Press, Milwaukee.
38. Parida, A. and Kumar, U. (2004), "Application of overall equipment effectiveness (OEE) as a process performance indicator: a case study from Kiruna mines", *Proceedings of ENTMS Aneswar, Bhubaneswar*, 11-12 May
39. Peter Muchiri, Liliane Pintelon, Ludo Gelders and Harry Martin, (2011) "Development of maintenance function performance measurement framework and indicators", *International Journal of Production Economics*, Volume 131, pp 295 – 302.
40. Pritibhushan Sinha, (2015) "Towards higher maintenance effectiveness: Integrating maintenance management with reliability engineering", *International Journal of Quality & Reliability Management*, Vol. 32 Issue: 7, pp.754-76.
41. Probert, S.D., Ogaji, S.O.T. and Eti, M.C. (2006), "Development and implementation of preventive maintenance practices in Nigerian industries", *Applied Energy*, Vol.83No.10,pp.1163-1179
42. Ravi Kumar Goyal and Kapil Maheshwari, (2012), "Maintenance Management Practices: a retrospective and literature review", *Journal of Advainces in Engineering Research*, Volume3, issue 2.
43. Renjit Kumar (2011), 'Research methodology step by step guides for beginners' 3rd edition, Sage publication.
44. Richard Doc Palmer, (2006) "maintenance Planning and Scheduling Handbook", McGraw-Hill USA.
45. S. A. Brah & W.-K. Chong (2004) Relationship between total productive maintenance and performance, *International Journal of Production Research*, volume 42 Issue No.12, pp 2383-2401.
46. Salonen A. (2009) Formulation of maintenance strategies. School of Innovation, Design and Engineering. Västerås: Mälardalen University Licentiate Theses No. 100.
47. Sandeep Phogat, Anil Kumar Gupta, (2017) "Identification of problems in maintenance operations and comparison with manufacturing operations: A review", *Journal of Quality in Maintenance Engineering*, Vol. 23 Issue: 2, pp.226-238
48. Sandeep Phogat, Anil Kumar Gupta, (2017) "Identification of problems in maintenance operations and comparison with manufacturing operations: A review", *Journal of Quality in Maintenance Engineering*, Vol. 23 Issue: 2, pp.226-238.
49. Sharma, R., Kumar, D. and Kumar, P. (2005), "FLM to select suitable maintenance strategy in process industries using MISO model", *Journal of Quality in Maintenance Engineering*, Vol. 11 No. 4, pp. 359-374.
50. Swanson L. (2001) Linking maintenance strategies to performance. *International Journal of Production Economics*, vol. 70, no 3, pp. 237-244.

51. Tixier, J. et al., (2002) "Review of 62 risk analysis methodologies of industrial plants", *Journal of Loss Prevention in the Process Industries*, volume 15, issue no. 4, pp.291–303.
52. Tsuchiya, S., 1992. *Quality Maintenance: Zero Defects Through Equipment Management*, Productivity Press, Cambridge, MA.
53. Uday Kumar, Diego Galar, Aditya Parida, Christer Stenström, Luis Berges, (2013) "Maintenance performance metrics: a state-of-the-art review", *Journal of Quality in Maintenance Engineering*, Vol. 19, Issue: 3, pp.233-277.
54. Umar Al-Turki, (2011) "A framework for strategic planning in maintenance: methodology and theory", *Journal of Quality in Maintenance Engineering* Vol. 17 No. 2, pp. 150-162.
55. Waeyenbergh, G. and Pintelon, L. (2002) A framework for maintenance concept development. *International Journal of Production Economics*, vol. 77, no 3, pp. 299-313.
56. Zweckhorst, A.(1996), Evolution of maintenance, *Maintenance Technology* pp,9–14.

Appendix A

Questionnaire

PART I: General information

1. Position: _____
2. Total year of experience: _____
3. Experience at Asku plc. _____
4. Educational background: _____
5. How many employees do you have under you? _____

PART II: Maintenance management

6. How do you rate machine performance of Asku plc.?

| | | | |
|--------------------------|-----------|--------------------------|-----------|
| <input type="checkbox"/> | Very poor | <input type="checkbox"/> | Good |
| <input type="checkbox"/> | Poor | <input type="checkbox"/> | Very Good |
| <input type="checkbox"/> | Average | <input type="checkbox"/> | Excellent |

7. What is the reason for this performance?

8. Do you maintain an equipment?

| | | | |
|--------------------------|-----|--------------------------|----|
| <input type="checkbox"/> | Yes | <input type="checkbox"/> | No |
|--------------------------|-----|--------------------------|----|

9. Does your immediate superior support you?

| | | | |
|--------------------------|--------------------|--------------------------|--------|
| <input type="checkbox"/> | Always/ very often | <input type="checkbox"/> | Rarely |
| <input type="checkbox"/> | Sometimes/ often | <input type="checkbox"/> | Never |
| <input type="checkbox"/> | Occasionally | | |

10. How many machine types do you maintain?

| | | | |
|--------------------------|---|--------------------------|----|
| <input type="checkbox"/> | 1 | <input type="checkbox"/> | 4 |
| <input type="checkbox"/> | 2 | <input type="checkbox"/> | 5 |
| <input type="checkbox"/> | 3 | <input type="checkbox"/> | >5 |

11. Is there a good communication between maintenance and production department?

| | | | |
|--------------------------|--------------------|--------------------------|--------|
| <input type="checkbox"/> | Always/ very often | <input type="checkbox"/> | Rarely |
| <input type="checkbox"/> | Sometimes/ often | <input type="checkbox"/> | Never |
| <input type="checkbox"/> | Occasionally | | |

12. Maintenance of production equipment is seen as a strategic factor within the organization.

| | | | |
|--------------------------|---------------|--------------------------|------------------|
| <input type="checkbox"/> | Totally Agree | <input type="checkbox"/> | Disagree |
| <input type="checkbox"/> | Agree | <input type="checkbox"/> | totally disagree |
| <input type="checkbox"/> | Indifferent | | |

13. Does Asku Plc has maintenance strategy?

| | | | |
|--------------------------|-----|--------------------------|----|
| <input type="checkbox"/> | Yes | <input type="checkbox"/> | No |
|--------------------------|-----|--------------------------|----|

14. If your answer for question 5 is yes, what type of maintenance strategy are you following?

- Preventive maintenance
- Corrective maintenance
- Breakdown maintenance
- Predictive
- Other, please mention _____

15. If your answer for question 5 is No, why

16. Does an equipment fail repeatedly?

- Yes No

17. Is a quick response being there to repair an equipment?

- Always Rarely
 Sometimes Never

18. Do you recognize any failure before it happens?

- Always Rarely
 Sometimes Never

19. How many machines do you outsource for maintenance?

- 1 4
 2 5
 3 >5

20. To whom do you outsource maintenance of a machine?

- Machine supplier Experts for that specific machine

21. What causes machine breakdown

- Lack of proper maintenance
- Shortage of manpower
- Shortage of required spare parts
- Unavailability of required tools and equipment's
- Lack of skilled manpower
- Lack of training of technical team
- Lack of employee commitment
- Others, please mention _____

22. What type of maintenance strategy do you follow in your assigned area?

- Preventive maintenance
- Corrective maintenance
- Breakdown maintenance
- Predictive maintenance
- Other, _____

23. What techniques do you use to analyze failures?

- Failure mode and effect analysis (FMEA)
- Root cause analysis(RCA)
-
-

- Failure tree analysis(FTA)
- Plan- do-check-act(PDCA)
- Cause and effect analysis
- 5S
- 5whys
- No technique used
- Other, _____

24. Do you have a suitable tool in maintenance department?

- Yes No

25. What is the condition of these tools?

- New Like new
 Old Broken

26. Do you keep these tools in a suitable location?

- Yes No
 Take long time to find it a special box

27. What is the reason for outsourcing?

28. What should be done to solve frequent machine breakdowns?

Part III: Maintenance Indicators

29. What type of maintenance performance indicators used?

- | | | | |
|--------------------------|-----------------|--------------------------|---------------------|
| <input type="checkbox"/> | OEE | <input type="checkbox"/> | Backlog |
| <input type="checkbox"/> | MTBF by machine | <input type="checkbox"/> | Availability |
| <input type="checkbox"/> | MTBF by line | <input type="checkbox"/> | Downtime |
| <input type="checkbox"/> | MTTR by machine | <input type="checkbox"/> | Economic indicators |
| <input type="checkbox"/> | MTTR by line | <input type="checkbox"/> | No indicator used |
| <input type="checkbox"/> | Other, | | |

Part IV maintenance plan and procedures

30. Do you have a maintenance plan?

- Yes No

31. do you have adequate maintenance procedures in place?

- Yes No

32. Frequency of maintenance plan?

- Daily
 Weekly
 Monthly
 Semiannually

- Yearly
 No maintenance plan

33. What activities do you do in your assigned areas

| s. no. | Frequency | Activities |
|--------|--------------|------------|
| 1 | Daily | |
| 2 | Weekly | |
| 3 | Monthly | |
| 4 | Semiannually | |
| 5 | Yearly | |

34. What method do you use to record maintenance records?

- Computer based maintenance management system
 Spreadsheet
 Manual paper recording

35. If you use CMMS, Is that system up to date?

- Yes No

PART V. Maintenance staff

36. How is the organizational structure of maintenance department? Draw the maintenance department organizational structure.

37. Do the department has training schedule?

- Yes No

38. Does training is providing to maintenance staffs as per the schedule?

- Yes No

39. Please put a right mark (v) on your answer

| S. no. | Activity | Never | Rarely | Occasi- onally | Often | Very often |
|--------|---|-------|--------|-------------------|-------|---------------|
| 1 | Maintenance technicians receive training in the production process and method of operation. | | | | | |
| 2 | Maintenance technicians receive training on equipment. | | | | | |
| 3 | Technicians receive training in methodologies, techniques and tools to help maintenance management. | | | | | |

Thank you for your cooperation!

Appendix B

Over All Equipment Effectiveness calculation table.

Appendix B1. OEE of blower machine

| Month | Planned hour | Down time | Availability | planned Quantity | Actual Quantity | Performance | Total Output | Reject qty | Quality | OEE of Blower machine |
|---------------|--------------|-----------|--------------|------------------|-----------------|-------------|--------------|------------|---------|-----------------------|
| Meskerem 2009 | 1,371.46 | 99.00 | 92.78% | 10,561,084 | 6,978,055 | 66.07% | 6,978,055 | 178,718 | 97.50% | 59.77% |
| Tikimt 2009 | 1,620.00 | 258.00 | 84.07% | 13,045,060 | 7,984,313 | 61.21% | 7,984,313 | 219,321 | 97.33% | 50.08% |
| Hidar 2009 | 2,164.04 | 309.40 | 85.70% | 17,343,571 | 9,922,353 | 57.21% | 9,922,353 | 241,006 | 97.63% | 47.87% |
| Tahisas 2009 | 1,547.00 | 212.20 | 86.28% | 12,745,460 | 7,155,900 | 56.14% | 7,155,900 | 249,149 | 96.64% | 46.81% |
| Tir 2009 | 1,985.45 | 356.10 | 82.06% | 14,665,410 | 8,000,299 | 54.55% | 8,000,299 | 307,800 | 96.30% | 43.11% |
| Yekatit 2009 | 2,276.20 | 267.80 | 88.23% | 17,310,360 | 10,620,313 | 61.35% | 10,620,313 | 315,023 | 97.12% | 52.57% |
| Megabit 2009 | 2,090.32 | 215.20 | 89.70% | 16,099,294 | 10,644,831 | 66.12% | 10,644,831 | 343,440 | 96.87% | 57.46% |
| Miyazia 2009 | 2,011.30 | 288.30 | 85.67% | 15,747,680 | 10,353,455 | 65.75% | 10,353,455 | 276,276 | 97.40% | 54.86% |
| Ginbot 2009 | 2,036.37 | 261.70 | 87.15% | 15,361,575 | 9,299,148 | 60.54% | 9,299,148 | 325,800 | 96.62% | 50.97% |
| Sene 2009 | 1,918.00 | 234.50 | 87.77% | 14,582,630 | 7,934,629 | 54.41% | 7,934,629 | 244,359 | 97.01% | 46.33% |
| Hamle 2009 | 1,860.29 | 103.60 | 94.43% | 12,897,130 | 7,610,653 | 59.01% | 7,610,653 | 158,736 | 97.96% | 54.59% |
| Nehasse 2009 | 1,647.00 | 159.00 | 90.35% | 11,558,300 | 5,859,600 | 50.70% | 5,859,600 | 115,775 | 98.06% | 44.91% |
| Meskerem 2010 | 1,163.08 | 79.50 | 93.16% | 8,063,170 | 4,324,384 | 53.63% | 4,324,384 | 210,552 | 95.36% | 47.65% |

Appendix B2. OEE of filler machine

| Month | Planned hour | Down time | Availability | planned Quantity | Actual Quantity | Performance | Total Output | Reject qty | Quality | OEE of Blower machine |
|---------------|--------------|-----------|--------------|------------------|-----------------|-------------|--------------|------------|---------|-----------------------|
| Meskerem 2009 | 1,371.46 | 78.50 | 94.28% | 10,561,084 | 6,978,055 | 66.07% | 6,978,055 | 101,001 | 98.57% | 61.40% |
| Tikimt 2009 | 1,620.00 | 51.90 | 96.80% | 13,045,060 | 7,984,313 | 61.21% | 7,984,313 | 134,850 | 98.34% | 58.26% |
| Hidar 2009 | 2,164.04 | 75.20 | 96.53% | 17,343,571 | 9,922,353 | 57.21% | 9,922,353 | 166,119 | 98.35% | 54.31% |
| Tahisas 2009 | 1,547.00 | 99.40 | 93.57% | 12,745,460 | 7,155,900 | 56.14% | 7,155,900 | 139,781 | 98.08% | 51.53% |
| Tir 2009 | 1,985.45 | 72.80 | 96.33% | 14,665,410 | 8,000,299 | 54.55% | 8,000,299 | 184,860 | 97.74% | 51.37% |
| Yekatit 2009 | 2,276.20 | 62.10 | 97.27% | 17,310,360 | 10,620,313 | 61.35% | 10,620,313 | 145,132 | 98.65% | 58.87% |
| Megabit 2009 | 2,090.32 | 61.10 | 97.08% | 16,099,294 | 10,644,831 | 66.12% | 10,644,831 | 173,789 | 98.39% | 63.16% |
| Miyazia 2009 | 2,011.30 | 66.00 | 96.72% | 15,747,680 | 10,353,455 | 65.75% | 10,353,455 | 145,905 | 98.61% | 62.70% |
| Ginbot 2009 | 2,036.37 | 100.80 | 95.05% | 15,361,575 | 9,299,148 | 60.54% | 9,299,148 | 217,291 | 97.72% | 56.22% |
| Sene 2009 | 1,918.00 | 95.20 | 95.04% | 14,582,630 | 7,934,629 | 54.41% | 7,934,629 | 140,156 | 98.26% | 50.81% |
| Hamle 2009 | 1,860.29 | 98.70 | 94.69% | 12,897,130 | 7,610,653 | 59.01% | 7,610,653 | 75,493 | 99.02% | 55.33% |
| Nehasse 2009 | 1,647.00 | 71.60 | 95.65% | 11,558,300 | 5,859,600 | 50.70% | 5,859,600 | 97,242 | 98.37% | 47.70% |
| Meskerem 2010 | 1,163.08 | 66.40 | 94.29% | 8,063,170 | 4,324,384 | 53.63% | 4,324,384 | 131,564 | 97.05% | 49.08% |

Appendix B3. OEE of neck sleeve machine

| Month | Planned hour | Down time | Availability | planned Quantity | Actual Quantity | Performance | Total Output | Reject qty | Quality | OEE of Blower machine |
|---------------|--------------|-----------|--------------|------------------|-----------------|-------------|--------------|------------|---------|-----------------------|
| Meskerem 2009 | 1,371.46 | - | 100.00% | 10,561,084 | 6,978,055 | 66.07% | 6,978,055 | 60,188 | 99.14% | 65.51% |
| Tikimt 2009 | 1,620.00 | - | 100.00% | 13,045,060 | 7,984,313 | 61.21% | 7,984,313 | 38,714 | 99.52% | 60.91% |
| Hidar 2009 | 2,164.04 | - | 100.00% | 17,343,571 | 9,922,353 | 57.21% | 9,922,353 | 202,570 | 98.00% | 56.07% |
| Tahisas 2009 | 1,547.00 | - | 100.00% | 12,745,460 | 7,155,900 | 56.14% | 7,155,900 | 240,715 | 96.75% | 54.32% |
| Tir 2009 | 1,985.45 | - | 100.00% | 14,665,410 | 8,000,299 | 54.55% | 8,000,299 | 117,813 | 98.55% | 53.76% |
| Yekatit 2009 | 2,276.20 | - | 100.00% | 17,310,360 | 10,620,313 | 61.35% | 10,620,313 | 360,039 | 96.72% | 59.34% |
| Megabit 2009 | 2,090.32 | - | 100.00% | 16,099,294 | 10,644,831 | 66.12% | 10,644,831 | 285,690 | 97.39% | 64.39% |
| Miyazia 2009 | 2,011.30 | 32.23 | 98.40% | 15,747,680 | 10,353,455 | 65.75% | 10,353,455 | 564,505 | 94.83% | 61.35% |
| Ginbot 2009 | 2,036.37 | 29.40 | 98.56% | 15,361,575 | 9,299,148 | 60.54% | 9,299,148 | 425,736 | 95.62% | 57.05% |
| Sene 2009 | 1,918.00 | 28.30 | 98.52% | 14,582,630 | 7,934,629 | 54.41% | 7,934,629 | 268,068 | 96.73% | 51.86% |
| Hamle 2009 | 1,860.29 | 20.00 | 98.92% | 12,897,130 | 7,610,653 | 59.01% | 7,610,653 | 60,762 | 99.21% | 57.91% |
| Nehasse 2009 | 1,647.00 | 42.10 | 97.44% | 11,558,300 | 5,859,600 | 50.70% | 5,859,600 | 123,436 | 97.94% | 48.38% |
| Meskerem 2010 | 1,163.08 | 23.70 | 97.96% | 8,063,170 | 4,324,384 | 53.63% | 4,324,384 | 138,160 | 96.90% | 50.91% |

Appendix B4 OEE of Labeler machine

| Month | Planned hour | Down time | Availability | planned Quantity | Actual Quantity | Performance | Total Output | Reject qty | Quality | OEE of Blower machine |
|---------------|--------------|-----------|--------------|------------------|-----------------|-------------|--------------|------------|---------|-----------------------|
| Meskerem 2009 | 1,371.46 | 19.30 | 98.59% | 10,561,084 | 6,978,055 | 66.07% | 6,978,055 | 61,791 | 99.12% | 64.57% |
| Tikimt 2009 | 1,620.00 | 48.10 | 97.03% | 13,045,060 | 7,984,313 | 61.21% | 7,984,313 | 58,503 | 99.27% | 58.96% |
| Hidar 2009 | 2,164.04 | 36.20 | 98.33% | 17,343,571 | 9,922,353 | 57.21% | 9,922,353 | 105,728 | 98.95% | 55.66% |
| Tahisas 2009 | 1,547.00 | 68.30 | 95.59% | 12,745,460 | 7,155,900 | 56.14% | 7,155,900 | 137,253 | 98.12% | 52.66% |
| Tir 2009 | 1,985.45 | 62.20 | 96.87% | 14,665,410 | 8,000,299 | 54.55% | 8,000,299 | 205,715 | 97.49% | 51.52% |
| Yekatit 2009 | 2,276.20 | 51.80 | 97.72% | 17,310,360 | 10,620,313 | 61.35% | 10,620,313 | 182,660 | 98.31% | 58.94% |
| Megabit 2009 | 2,090.32 | 62.50 | 97.01% | 16,099,294 | 10,644,831 | 66.12% | 10,644,831 | 488,736 | 95.61% | 61.33% |
| Miyazia 2009 | 2,011.30 | 35.10 | 98.25% | 15,747,680 | 10,353,455 | 65.75% | 10,353,455 | 200,724 | 98.10% | 63.37% |
| Ginbot 2009 | 2,036.37 | 39.20 | 98.08% | 15,361,575 | 9,299,148 | 60.54% | 9,299,148 | 355,031 | 96.32% | 57.19% |
| Sene 2009 | 1,918.00 | 49.70 | 97.41% | 14,582,630 | 7,934,629 | 54.41% | 7,934,629 | 154,428 | 98.09% | 51.99% |
| Hamle 2009 | 1,860.29 | 47.30 | 97.46% | 12,897,130 | 7,610,653 | 59.01% | 7,610,653 | 90,055 | 98.83% | 56.84% |
| Nehasse 2009 | 1,647.00 | 52.80 | 96.79% | 11,558,300 | 5,859,600 | 50.70% | 5,859,600 | 83,984 | 98.59% | 48.38% |
| Meskerem 2010 | 1,163.08 | 39.20 | 96.63% | 8,063,170 | 4,324,384 | 53.63% | 4,324,384 | 93,529 | 97.88% | 50.73% |

Appendix B5

| Month | Planned hour | Down time | Availability | planned Quantity | Actual Quantity | Performance | Total Output | Reject qty | Quality | OEE of Blower machine |
|---------------|--------------|-----------|--------------|------------------|-----------------|-------------|--------------|------------|---------|-----------------------|
| Meskerem 2009 | 1,371.46 | 7.90 | 99.42% | 10,561,084 | 6,978,055 | 66.07% | 6,978,055 | 64,562 | 99.08% | 65.09% |
| Tikimt 2009 | 1,620.00 | 19.20 | 98.81% | 13,045,060 | 7,984,313 | 61.21% | 7,984,313 | 32,803 | 99.59% | 60.23% |
| Hidar 2009 | 2,164.04 | 37.20 | 98.28% | 17,343,571 | 9,922,353 | 57.21% | 9,922,353 | 101,491 | 98.99% | 55.66% |
| Tahisas 2009 | 1,547.00 | 37.40 | 97.58% | 12,745,460 | 7,155,900 | 56.14% | 7,155,900 | 90,912 | 98.75% | 54.10% |
| Tir 2009 | 1,985.45 | 60.70 | 96.94% | 14,665,410 | 8,000,299 | 54.55% | 8,000,299 | 154,854 | 98.10% | 51.88% |
| Yekatit 2009 | 2,276.20 | 43.70 | 98.08% | 17,310,360 | 10,620,313 | 61.35% | 10,620,313 | 131,481 | 98.78% | 59.44% |
| Megabit 2009 | 2,090.32 | 45.20 | 97.84% | 16,099,294 | 10,644,831 | 66.12% | 10,644,831 | 498,644 | 95.53% | 61.80% |
| Miyazia 2009 | 2,011.30 | 68.20 | 96.61% | 15,747,680 | 10,353,455 | 65.75% | 10,353,455 | 326,038 | 96.95% | 61.58% |
| Ginbot 2009 | 2,036.37 | 42.50 | 97.91% | 15,361,575 | 9,299,148 | 60.54% | 9,299,148 | 125,736 | 98.67% | 58.48% |
| Sene 2009 | 1,918.00 | 43.20 | 97.75% | 14,582,630 | 7,934,629 | 54.41% | 7,934,629 | 221,585 | 97.28% | 51.74% |
| Hamle 2009 | 1,860.29 | 76.80 | 95.87% | 12,897,130 | 7,610,653 | 59.01% | 7,610,653 | 33,256 | 99.56% | 56.33% |
| Nehasse 2009 | 1,647.00 | 50.00 | 96.96% | 11,558,300 | 5,859,600 | 50.70% | 5,859,600 | 47,433 | 99.20% | 48.76% |
| Meskerem 2010 | 1,163.08 | 32.20 | 97.23% | 8,063,170 | 4,324,384 | 53.63% | 4,324,384 | 89,831 | 97.96% | 51.09% |

Appendix B6. Summary of OEE.

| Months | Blower machine | Filler machine | Sleeve machine | Labeler machine | Packer machine |
|---------------|----------------|----------------|----------------|-----------------|----------------|
| Meskerem 2009 | 59.77% | 61.40% | 65.51% | 64.57% | 65.09% |
| Tikimt 2009 | 50.08% | 58.26% | 60.91% | 58.96% | 60.23% |
| Hidar 2009 | 47.87% | 54.31% | 56.07% | 55.66% | 55.66% |
| Tahisas 2009 | 46.81% | 51.53% | 54.32% | 52.66% | 54.10% |
| Tir 2009 | 43.11% | 51.37% | 53.76% | 51.52% | 51.88% |
| Yekatit 2009 | 52.57% | 58.87% | 59.34% | 58.94% | 59.44% |
| Megabit 2009 | 57.46% | 63.16% | 64.39% | 61.33% | 61.80% |
| Miyazia 2009 | 54.86% | 62.70% | 61.35% | 63.37% | 61.58% |
| Ginbot 2009 | 50.97% | 56.22% | 57.05% | 57.19% | 58.48% |
| Sene 2009 | 46.33% | 50.81% | 51.86% | 51.99% | 51.74% |
| Hamle 2009 | 54.59% | 55.33% | 57.91% | 56.84% | 56.33% |
| Nehasse 2009 | 44.91% | 47.70% | 48.38% | 48.38% | 48.76% |
| Meskerem 2010 | 47.65% | 49.08% | 50.91% | 50.73% | 51.09% |

Appendix C.

Severity Guidance for system FMEA

| Effect | Rank | Criteria |
|-------------|------|--|
| None | 1 | No Effect |
| Very Slight | 2 | Customer not annoyed. Very slight effect on product or system performance. |
| Slight | 3 | Customer slightly annoyed. Slight effect on product or system performance. |
| Minor | 4 | Customer experiences minor nuisance. Minor effect on product or system performance. |
| Moderate | 5 | Customer experiences some dissatisfaction. Moderate effect on product or system performance. |
| Significant | 6 | Customer experiences discomfort. Product performance degraded, but operable and safe. Partial failure, but operable. |
| Major | 7 | Customer dissatisfied. Product performance severely affected but functional and safe. System impaired. |
| Extreme | 8 | Customer very dissatisfied. Product inoperable but safe. System inoperable. |
| Serious | 9 | Potential hazardous effect. Able to stop product without mishap – time dependent failures. Compliance with government regulation is in jeopardy. |
| Hazardous | 10 | Hazardous effect. Safety related – sudden failure. Noncompliance with government regulation. |

Ref: Failure Mode Effect Analysis: FMEA from Theory to Execution, by D. H. Stamatis

Occurrence Guidance for system FMEA

| Effect | Rank | Criteria | CNF/1000 |
|--------------------|------|--|----------|
| Almost Never | 1 | Failure unlikely, history shows no failures | < .00058 |
| Remote | 2 | Rare number of failures likely | .0068 |
| Very Slight | 3 | Very few failures likely | .0063 |
| Slight | 4 | Few failures likely | .46 |
| Low | 5 | Occasional number of failures likely | 2.7 |
| Medium | 6 | Medium number of failures likely | 12.4 |
| Moderately High | 7 | Moderately high number of failures likely | 46 |
| High | 8 | High number of failures likely | 134 |
| Very High | 9 | Very High number of failures likely | 316 |
| Almost Certain | 10 | Failure almost certain. History of failures exists from previous or similar designs. | >316 |

Ref: Failure Mode Effect Analysis: FMEA from Theory to Execution, by D. H. Stamatis

Detection Guidance for system FMEA

| Effect | Rank | Criteria |
|----------------------|------|---|
| Almost certain | 1 | Proven detection methods available while in conceptual design |
| Very High | 2 | Has very high effectiveness |
| High | 3 | Has high effectiveness |
| Moderately High | 4 | Has moderately high effectiveness |
| Medium | 5 | Has medium effectiveness |
| Low | 6 | Has low effectiveness |
| Slight | 7 | Has very low effectiveness |
| Very Slight | 8 | Has lowest effectiveness in each applicable category |
| Remote | 9 | Unproven, or unreliable, or effectiveness is unknown |
| Almost Impossible | 10 | No technique is available or known, and/or none is planned |

Ref: Failure Mode Effect Analysis: FMEA from Theory to Execution, by D. H. Stamatis