# Investigation and Analysis of Maintenance Strategy in Metahara Sugar Factory to Enhance Productivity

**Sultan Kasim Tufa**

A Thesis Submitted to the Department of Mechanical Engineering

School of Mechanical, Chemical and Materials Engineering

Presented in Partial Fulfillment of the Requirement for the Degree of

Master's in Manufacturing Engineering

Office of Graduate Studies

Adama Science and Technology University

July, 2023

Adama, Ethiopia

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**Advisor: Moera Gutu Jiru (Associate professor)**

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**Declaration**

I hereby declare that this Master Thesis entitled "Investigation and Analysis of Maintenance Strategy in Metahara Sugar Factory to Enhance Productivity" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

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Therefore, I/We recommend the submission of revised version of the thesis to the department following the applicable procedures.

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**Abbreviation**

| | |
|---|---|
| EFNMS | European federation of National Maintenance |
| LP | Linear programming |
| MSF | Metahara Sugar Factory |
| OEE | Overall Equipment Efficiency |
| PM | Preventive Maintenance |
| PdM | Predictive Maintenance |
| RCA | Root Cause Analysis |
| RCM | Reliability Centered Maintenance |
| SPC | Statistical Process Control |
| TBF | Time Between Failures |
| TCD | Tons of Cane Crushed per Day |
| TPM | Total productivity Maintenance |
| TQM | Total Quality Management |
| MA | Milling A |
| CHA | Cane handling A |
| MB | Milling B |
| CHB | Cane handling B |
| CHPA | Cane handling plant A |
| MPA | Milling plant A |
| CHPB | Cane handling plant B |
| MPB | Milling plant B |
| Mech.Dt | Mechanical down time |
| Elec.Dt | Electrical down time |
| Inst.Dt | Instrument down times |
| Block.Dt | Blockage down time |
| Other.Dt | Other down time |
| Prev.maint.Dt | Preventive maintenance down time |
| Pressure dropDt | Pressure drop down times |
| Lack of steam.Dt | Lack of steam down time |

***Abstract***

*Metahara Sugar Factory was started sugar production in 1970GC. Productivity of the factory is facing many challenges due to raw material input, machinery performance due to failure, shutdown and professional workers skill and motivation. This thesis research was aimed to collect different data from planning, production, quality and maintenance department to collect primary and secondary data in order to investigate production bottlenecks for five consequentive years from 2017/018 to 2021/022 GC. Questioners were distributed to different sections, documentation of different data on plan, production, down time were gathered. Factory visited and interviews were conducted to concerned section. The data were analyzed using different tools such as bar charts, histogram, line charts, pie charts, Statistical Package for Social Sciences (SPSS) software and others to reach on conclusion. Multiple linear regression models using Minitab software was used to get a regression model of statistically significant with a P value less than 0.001 and had an R-squared value of 98.98%.The performance result of the factory from 2017/2018 to 2021/2022 was 68,137.40tons, 63,311.20 tons, 595.10 tons, 76,266.60 tons and 44,472.60 tons of sugar respectively and the production plan was97,175.10tons, 95,000.00tons, 100,296.20 tons, 97,163.00 tons and 95,000.00tons for each year respectively. While the productivity calculated with ratio of sugar produced to cane crushed was 0.87, 0.848, 0.83, 0.89 and 0.89 respectively for the five consequentive years. The productivity bottleneck of the factory were machineries downtimes due to mechanical, electrical, instrument, blockage, others, preventive maintenance, pressure drop and lack of steam. Among total factory down times recorded for consequentive five years, the 2019/20 campaign year was the highest which was 3721.83hours and exposed for high maintenance cost which was 576,154,477.22 birr.*

*In current study to improve productivity multiple linear regression model was developed by Minitab software from factory down time data to predict the optimum value at which the productivity will be high by 10.2% profitability margin. Finally, to achieve the optimized down time the organization should use the preventive and predictive maintenance strategy and rather breakdown maintenance which was highly used in the factory.*

**Keyword:** maintenance, breakdowns, productivity, optimization, multiple regression model, sugar production

# CHAPTER-1

# INTRODUCTION

## 1.1 Introduction

This chapter describes the background information, the statement of the problem, objectives of the study, motivation, significance of the study, scope of the study and limitation of the study.

### 1.2 Background of the study

(Er-ratby and Mabrouki ,2018) 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 rapidly changing marketplace, slow and steady improvements in manufacturing operations do not guarantee sustained profitability or organizational survival. Thus, the organizations need to improve at a faster rate than their competitors if they are to become or remain leaders in the industry (Ismail and Kamal, 2020). (Bakri et al., 2020) shows that 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 of equipment and facilities, there is no doubt that maintenance costs can be high and often representing a significant portion of recurrent budgets(Fraser and Tseng 2015).

The link between productivity improvement and maintenance is well established. Proper maintenance maximizes the performance and availability of machinery, which leads to increased productivity. Equipment effectiveness is no longer restricted to availability, but involves other factors, such as quality and efficiency. The impact of maintenance on business performance aspect such as productivity and profitability has increased indefinitely in recent times due to its role in ensuring and improving machine availability, performance efficiency, product quality and swift delivery, environmental and safety requirements (Swanson, 2001).

The company data report from quality, planning, technical and production departments indicated that the production performance of the past five year’s i.e from 2017/18 – 2021/2022 operation campaign years was 67.6% which was low performance. From the factory data this year (2022/2023) the factory performance was 58%, which was very low performance.

The main reasons that hinder the company not to achieved the target was mainly due to machineries down time and other stoppages. This indicated that there was a maintenance problem in the factory. Therefore, the study addressed the maintenance problem by investigation of maintenance strategy analysis to enhance productivity in Metahara Sugar factory.

### 1.3 Sugar production process

The sugar production process broadly classified in to eight main plants in Metahara Sugar Factory. These were:-cane handling, extraction plant, clarification, evaporation, vacuum, centrifugal, bagging floor, boiler and power station.

**Cane preparation:** The cane carrier is the moving apron which conveys the cane into the factory and which ensures consistent feed to the mills by transporting the cane from the yard to the crusher. Since effective feeding of the crusher requires an elevated hopper, and the cane must be raised to this high level from the level of the yard, where the carrier is generally in a pit, the carrier always includes a sloping portion. The cane carrier consists of knives and hammers to break down the cane before passing it through to a crusher and shredder. The crusher is the first machine applying pressure which the cane encounters on arriving at the milling plant (Elamin, 2017).

**Juice Extraction System:** The juice is extracted from the cane either by milling, in which the cane is pressed between the heavy rolls, or by diffusion, in which the sugar is leached out with water. The sugar cane bagasse produced at the extraction is delivered to the boiler plant, where it is used as fuel, producing the steam and electricity to the factory. The juice extracted from the cane is treated in the subsequent process to remove the non-sugar impurities (Kassahun, 2011).

**Clarification:** This involves separation of impurities from the juice by adding flocculants which will react with organic material and precipitation of non-sugar debris (mud) will follow. The clarification process gives clear juice to be sent to the evaporation process and mud which juice will be filtered further (Eyerusalem, 2016).

**Filtration:** This involves the filtration of the mud from the clarification process in order to separate suspended matter and insoluble salts formed (fine bagasse is entrained with these) from the juice (Eyerusalem, 2016).

**Juice Evaporation:** Evaporation is performed in two stages: initially in an evaporator station to concentrate the juice and then in vacuum pans to crystallize the sugar. The clarified juice is passed through heat exchangers to preheat the juice and then to the evaporator stations.

Evaporator stations consist of a series of evaporators, termed multiple-effect evaporators; typically, a series of four evaporators. Steam from large boilers is used to heat the first evaporator, and the steam from the water evaporated in the first evaporator is used to heat the second evaporator. This heat transfer process continues through the four evaporators and as the temperature decreases (due to heat loss) from evaporator to evaporator, the pressure inside each evaporator also decreases which allows the juice to boil at the lower temperatures in the subsequent evaporator. Some steam is released from the first three evaporators, and this steam is used in various process heaters in the plant. The evaporator station in cane sugar manufacture typically produces a syrup with about 60% solids and 40% water (Muwanika,2017).

**Syrup sulphitation:** syrup (concentrated clarified juice) from the evaporation system is sulphited to PH of about 5.5 by addition of the bleaching agent, $so_2$ gas, to improve the color of final product (Kassahun, 2011).

**Sugar Crystallization and Centrifugal Separation:** the sulphited syrup is further concentrated in the vacuum pans by boiling until a certain super saturation is reached. When the required super saturation is reached, seed crystals are added and the sucrose in the solution starts to deposition to these seed crystals. When the crystals reach the desired size the boiling process is stopped, resulting in a mixture of crystals and mother liquor known as massecuite. The massecuite from the pan is dropped in crystallizers and subsequently centrifuged in centrifugal machines for separating sugar crystals from mother liquor (molasses). The Crystals are washed, dried, cooled and sent to packaging or to storage. The mother liquor (molasses) again is sent back to pan for boiling and re-crystallization. Usually three stages of re-crystallization are adopted to ensure maximum recovery of sugar in crystal form. The final mother liquor referred to as final molasses is sent out of the factory as by-product being unsuitable for recovery of sugar under commercial conditions from economic point of view.

The schematic representation of cane plantation white sugar production in MSF shown in Figure 1.1(Kassahun, 2011).

On each process explained above factory down time occurs frequently due to machineries or components failure and these provide the decline of productivity from time to time.

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.

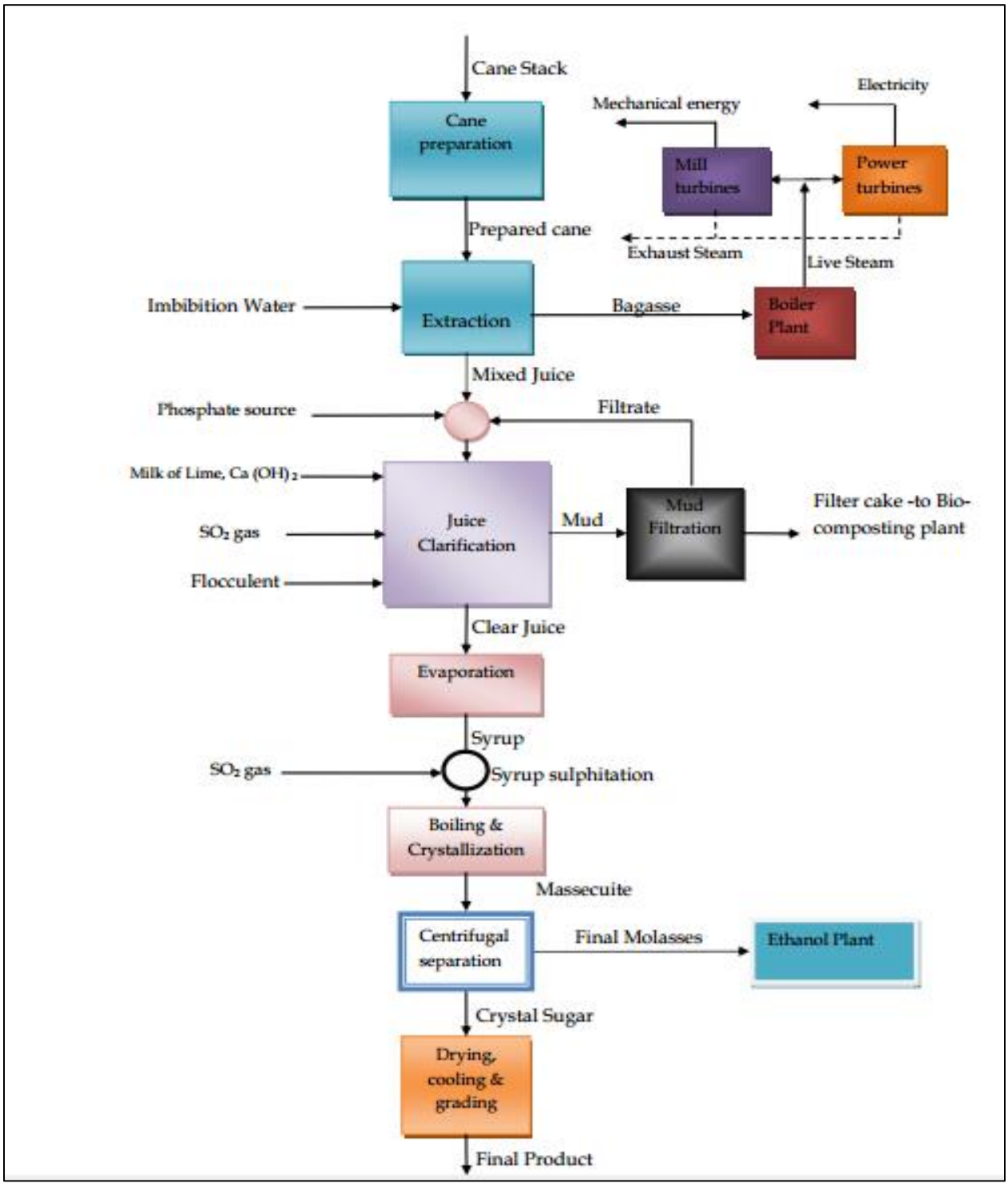



Figure 1.1 schematic representation of cane plantation white sugar production in MSF (Kassahun, 2011). As a result, equipment downtime, quality problems, speed losses or accidents, safety hazards or environmental pollution become the obvious outcomes. All

these outcomes had 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.

The main goal of MSF is to have an efficient and profitable operation with the required sugar quality and high productivity. One of the main problems in the factory is machineries down time. This is due to machineries are aged, unavailability of machineries spare parts, operation problem and maintenance problem. These provide the productivity declined to abnormal condition.

Appropriate maintenance of plant equipment and machineries significantly reduces overall operating cost of manufacturing. Additionally, it contributes to customer satisfaction through desired quality and on time delivery. The development of new technologies and managerial practices warrants maintenance crew to ensure having desired technical and managerial skills. Deterioration and failure of systems result to high costs, due to production losses and delays, unplanned intervention on the system and safety hazards. Therefore, appropriate maintenance strategy is necessary in order to prevent failure. Moreover, maintenance crew must select the most appropriate maintenance technique for each machine and manufacturing system out of a set of possible alternatives. In particular, the development of maintenance strategies (i.e. a suitable combination of corrective, preventive and predictive maintenance) must take into account that resource limitation affects maintenance quality (Baidya et al., 2016).

The current practices of the maintenance technique selection was mainly based on the operational criteria in line with machine specification giving utmost importance to the economic factors rather than framing the maintenance strategy based on the strategic importance in combination of technical requirements and efficiency.

### 1.4 Problem of statement

Many researchers studies conducted in sugar factory indicated that machinery maintenance has more impact on sugar productivity. However, studies show that still high machine breakdowns exist in Metahara Sugar Factory. The production of sugar is decreasing from time to time due to machineries down time and other factors (like lack of cane, rainy season which difficult to bring cane from flied). According to data record from quality control department for five years i.e

from 2017/18 to 2021/22 cane crushing campaign the machineries downtimes were the highest in 2019/2020 campaign year and the productivity was less as compared with other years. The down time recorded in this year was 3721.83hours which was 51.8%. A planned duration to cane crushing was 303 days or 7272 hours (10 months) which from factory data was written on appendix B, but the actual cane crushing time was 146 days or 3504 hours. This indicated that there were high machineries down times which have to be improved. The main reasons for high machineries down time were due to maintenance problems in the factory. Therefore, the existing Sugar factory needs to investigate maintenance strategy to minimize machineries down time, to increase productivity, to become competitive and profitable.

### 1.5. Basic Research Question

The research work consists of six main questions as a guiding question in order to meet the objectives and develop maintenance system to the company.

The questions include:

1. How is maintenance currently done for the machines in Metahara sugar factory?
2. What are the major problems in the current maintenance system on Metahara sugar factory?
3. What are the causes of poor maintenance in the Metahara sugar factory?
4. What improvements are needed to close the gaps between the current situation and the literature of Metahara Sugar Factory?
5. How can we verify and validate the maintenance concept in Metahara sugar factory?
6. What are the necessary steps to come to a maintenance concept and improve a maintenance concept in Metahara sugar factory?

### 1.6. Objectives

#### 1.6.1. General objective

The main objective of the thesis was an investigation of maintenance strategy analysis to improve productivity and minimize machineries down times.

#### 1.6.2. Specific objectives

In conducting the study the following specific objectives were addressed to achieve the general objective of the study.

1. To investigate productivity performance of Metahara Sugar Factory for five years.
2. To identify the failure rate of machines which are core production bottlenecks.

3. To investigate the major causes of break downs for selected machines.
4. To optimize down time by developing multiple linear regression using Minitab software of the predicted factory minimum down time.

**1.7 Motivation**

Downtime was an important subject in manufacturing because of its link to productivity and business profitability. Reducing downtime in production processes, including sugar production, therefore had become a necessity since it also serves the purpose of maximizing machine uptime. This is because productivity rises as the use of productive equipment increases. Machine downtime was one of the assignable causes of variation in a manufacturing system, resulting in poor production schedule reliability that should be minimized, if not completely eliminated. Machine downtime refers to off- the- time periods when machines are not productive or ready for assigned work. Although normally associated with manufacturing machines, the term can be used for any equipment usage (Nwanya, 2017).

Metahara sugar factory is the oldest sugar factory among the existing sugar factory and newly erupt projects in Ethiopia. The reduction of productivity and profit due mainly machineries down time which was mainly the result of maintenance strategy problem and other factors such as, ageing of machineries, operation problems, unavailability of machineries spare parts and others that cause machineries downtimes. So, the factory productivity decreases gradually due machineries down times to abnormal stage, so this motivate me to plan in-depth investigation maintenance strategy analysis in MSc thesis work.

**1.8 Significance of the study**

The research had a vital role to the company on bringing the expected target and played an endless role in keeping machines continuous performance and improved high machineries downtime, good productivity, reduced maintenance cost and increased product quality.

**1.9 Scope of the study**

The research focused on case study in Metahara Sugar Factory on maintenance practice, management system and any maintenance related issues.

**1.10 Organization of thesis**

The thesis work incorporates five main chapters including introduction, literature review, research methodology, data collection and analysis, and finally conclusion and recommendation. The first chapter is introduction and it briefly explains about the objectives,

problem statement, significant of the study and the second chapter, literature review, discusses various literatures on related subjects and previous works. The third chapter proposes appropriate research methodology and under the fourth chapter, data collection and analysis, collected data has been presented as well as root-cause analysis has been conducted and discussed. In the last chapter, conclusion and recommendation has been made and presents what should be done to ensure continuous improvement of production performance and productivity.

**1.11 Delamination of the study**

This thesis work limited to the following factors:

- The study not included down time during sugarcane harvesting and transportation up to the factory.
- Time schedule for this research work affected by different factors and tolerable to some extent.

# CHAPTER –2

# LITERATURE REVIEW

## 2.1 Introduction

The main objective of this section were to provide a description and prone and cons of common maintenance system and consider in detail, according to author's point of view, the most relevant for the current research.

## 2.2 Related literature review

Maintenance is defined according to the European standard as the 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 (Manohar and Kulkarni, 2022). According to ( Elias ,2020). The main goal of maintenance in an industrial plant is to achieve minimum downtime and to keep the equipment in operating condition at the lowest possible cost. The European Federation of National Maintenance Societies (EFNMS) defines maintenance as the combination of all technical, administrative and managerial actions used during the life cycle of equipment that are intended to retain or restore it to the state it can satisfactorily perform its required function. Points out that maintenance could be classified as: corrective maintenance, preventive maintenance, predictive maintenance, total productive maintenance (TPM) and reliability centered maintenance (RCM).

Maintenance involves functional checks, repairing or replacing necessary devices, machinery, and supporting utilities in industrial and governmental installations. Maintenance is keeping something in good condition. Performance measurement for maintenance systems can be based on various factors, and effective maintenance can reduce the consequences of failure and extend the life of a system. Implementation of maintenance refers to maintenance policies, which can be defined as the plans of action used to provide direction and guidelines to carry out further maintenance actions required by a system . In general, maintenance is defined as combining all technical and administrative actions, including supervision, which ensure that a system is in its required functioning state (Temesgen,2020).

Maintenance considerations play a key role during the life cycle of sugar equipment. The performance of sugar processing systems largely depends on the optimal utilization and

management of available resources. Availability, production cost and quality of sugar products is influenced by the condition of the equipment which are prone to stoppages due to unplanned failures if they are not well maintained. This affects production targets and costs in terms of downtime and inventory before the equipment is restored to operable state. Therefore sugar industries should have effective maintenance programs which are anchored on proper maintenance planning, scheduling, maintenance execution and sustainable improvement activities(Cornelius and Byiringiro,2018).

Maintenance is an important factor in quality assurance and in some cases determines the long-term success of a company. Poorly maintained resources can cause instability and partially or completely pause the production. Malfunctioning machines or complete breakdowns can become a costly process for most companies. When breakdowns occur the labor cost per unit rises as time passes until the machines again run as normal (Bakri et al., 2020).Any unplanned downtime of machinery equipment or devices would degrade or interrupt a company's core business, potentially resulting in significant penalties and un measurable reputation loss(Ran et al., 2019). It is important to point out that the sugar and alcohol production industries have as their main priority the planned corrective maintenance due to the seasonal characteristics of their operation, since there is great availability of time in the period known as off-season (approximately six months). In the food industry, the production line consists of machines interconnected by common transfer mechanisms with different failure modes. In the event of random failure in some equipment, most of the line interrupts the process, where the unfinished product should be discarded because of deterioration or quality problems, that is, the impact of the failure is negative and causes a decrease in reliability and production (Elias et al., 2020).

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(Er-ratby & Mabrouki, 2018)(Hwang & Samat, 2019).

The main idea of condition-based maintenance (CBM) is to utilize degradation information identified from on-line sensing techniques about equipment's physical characteristics and measures to minimize the system downtime by balancing the risk of failure and achievable profits (Fernández del Amo et al., 2018) and (Mkalaf,2016) says the majority of organizations that apply TPM or RCM gain the benefit of a reduction in machinery failure.

(Alsyouf, 2007) Affirm that the main task of production is to produce goods/ products. Nevertheless, efficient maintenance policy influences production capacity of machine used for producing these products. Maintenance therefore can be considered as an organizational function that functions in parallel with production. While reiterating that production produce product, the authors also express that maintenance produces the capacity for production. Thus, it can be said that maintenance affects production by increasing production capacity while also controlling the output quantity and quality.

An effective maintenance system is the bedrock of effective production system hence the evaluation of a maintenance culture is an important ingredient for improved profitability in manufacturing industries (Onawumi et al., 2021). Maintenance strategy is a planned way to upkeep devices, which contains actions such as identification, researching and execution of many repairs, replace and inspect decisions(Gackowiec, 2019). Maintenance strategy is as the set of various maintenance interventions (corrective, preventive, predictive, proactive, etc.) and the general structure in which these interventions are foreseen . Furthermore, explains three types of maintenance strategies: reactive strategy i.e, corrective maintenance; proactive strategy i.e, preventive and predictive maintenance; and aggressive strategy i.e, total productive maintenance. Maintenance strategy provides critical support for heavy and capital-intensive industries by keeping the productivity performance of plants and machineries in a reliable and safe operating condition(Lakhan et al., 2017).

Evaluating maintenance profitability, the impact on other working areas is also measured (e.g. by affirming maintenance role in machine life cycle profit). Maintenance improvements in general aim at reducing cost of operation and improving product quality, productivity, thus, the cost effectiveness of each improvement action may well be examined through evaluating the relevant cost constraint before and after improvements, a survey performed showed that 70% of the respondents considered maintenance as a cost center. Many studies have emphasized the role of maintenance in improving performance and profitability of manufacturing processes (Mushavhanamadi and Brian, 2018).

Literatures show that maintenance management is very important for the performance of the company (Palakodeti, 2019) (Ã, 2018)(Ismail et al., 2020)(Er-ratby & Mabrouki, 2018)(Bakri et al., 2020)(Fonseca et al., 2017)(Bakri et al., 2020)(Nuratirah & Salmiah, 2018).

The linear programming is the most often applied model of the optimization on account of the existence of finding efficient algorithms of optimal solution. The intuitiveness of linear relations appearing in the mathematical model (Mielczarek, 2018).

**2.3 Evolution of maintenance**

(Ogbannay and Uche, 2013) the first generation of maintenance started about 1940 till 1950. It is characterized by reactive mode which is mostly fixing equipment any time it fails (breakdown/corrective maintenance). The asset availability and reliability is not guaranteed and production losses and deferment are always encountered. Within this period, industry was not fully mechanized, so downtime did not matter much. This implies that prevention of equipment failure was not a priority. At the same time, most equipment was simple in design and can be easily repaired. Maintenance operations were simply cleaning, servicing and lubrication routines. Second generation of maintenance (1950 – 1977) improved on the first generation, where the focus is on preventive maintenance rather than corrective. The Second World War changed so many things. The war time pressures increased the demand for goods of all kinds while the supply of industrial manpower dropped sharply. This gave rise to increase in mechanization. Machines ranging from simple to complex ones were produced. Industries now depend on them to meet up targets in volume and quality. As this dependence grew, downtime came into sharper focus. The danger of not meeting production deadlines due to machine failure/downtime became a source of worry. This situation gave rise to the concept of preventive maintenance. The objective is to forestall any situation that can generate machine/equipment downtime in a

production system. The cost of maintenance started to rise relative to the other operating costs. This led to the growth of maintenance planning and control systems. These have helped to bring maintenance under control, and are now an established part of the practice of maintenance. The expectations of maintenance in the second generation of maintenance include higher equipment availability, longer equipment life and lower maintenance cost. The third generation of maintenance commenced from1978 – 2000. Since the mid-seventies, the process of change in the industry has gathered greater momentum. Equipment/machine failures and their inherent consequence of downtime are not tolerable. Downtime has always affected the productive capability of physical assets by reducing output, increasing operating costs and interfering with customer service. Therefore, the third generation of maintenance centers on predictive maintenance which have the following objectives:

- Higher plant availability and reliability.
- Greater safety
- Better product quality
- No damage to the environment
- Longer equipment life
- Greater cost effectiveness

The fourth generation of maintenance has a thrust in preventive maintenance. The whole essence of this concept is to improve plant availability and reliability at optimum cost as summarized below.

- Maximizing production or increasing facilities availability at the lowest cost and at the highest quality and safety standards.
- To ensure effective system optimization, eliminate equipment downtime and production deferment.
- Maintain high equipment availability and reliability, improving equipment efficiency and reducing scrap rate.
- Minimizing energy usage and optimising the useful life of equipment.
- To optimize maintenance resource cost within the constraints of safety and plant condition standards.
- Improving spares stock control

- Product unit cost reduction and profit maximization
- Providing reliable cost and budgetary control
- Identifying and implementing cost reductions.

**2.4 Maintenance types**

Maintenance is classified into two main categories, which are as follows

**2.4.1 Corrective Maintenance**

Corrective maintenance (CM): This is a system, in which the concept to prevent equipment failures is further expanded to be applied to the improvement of equipment so that the equipment failure can be eliminated (improving the reliability) and the equipment can be easily maintained (improving equipment maintainability). The primary difference between corrective and preventive maintenance is that a problem must exist before corrective actions are taken. The purpose of corrective maintenance is improving equipment reliability, maintainability, and safety; design weaknesses (material, shapes); existing equipment undergoes structural reform; to reduce deterioration and failures, and to aim at maintenance-free equipment. Maintenance information, obtained from CM, is useful for maintenance prevention for the next equipment and improvement of existing manufacturing facilities. It is important to form setups to provide the feedback of maintenance information (Ahuja,2008).

**2.4.2 Preventive Maintenance**

PM is the planned maintenance of plant infrastructure and equipment with the goal of improving equipment life by preventing excess depreciation and impairment. This maintenance includes, but is not limited to, adjustments, cleaning, lubrication, repairs, replacements and the extension of equipment life. It may appear to be unnecessary cost, as not doing PM does not immediately reflect in terms of breakdown cost or production downtime cost. Rather the small shutdown is taken for PM may be considered counter-productive (Dhingra, 2015).

**2.4.3 Condition Based Maintenance**

Arora, (2022) in this kind of maintenance, information on the current state of the system plays a very important factor. The state of the equipment is identified, and its health is analyzed to predict the possible failure in the system. Various statistical tools and techniques are used to process and analyze data collected from the equipment. Depending upon the information and state of the system, maintenance is carried out. This maintenance strategy can be used to save cost, downtime as some regular checks that are part of preventive maintenance strategy in many

companies can be avoided here. Condition-based maintenance is also referred as the alternative of predictive maintenance, but with more prominence to real time assessment. Wireless sensors/networks, Radio Frequency Identification (RFID) devices are used for monitoring and failure prediction in this type of maintenance. Other technologies such as Micro Electro-Mechanical System (MEMS), Supervisory Control And Data Acquisition (SCADA), Product Embedded Information Device (PEID) are also used for monitoring the status during the usage period. Some of the warning signs used for condition monitoring are temperature rise, vibrations, noise levels, cracks and deformation, particles release, resistance, etc. A condition-based maintenance strategy is a very dynamic and flexible approach. It determines maintenance decisions based on the deterioration state information of the system and therefore, a targeted maintenance plan can be formed. As a result, economic losses from the system breakdown and expenses from unnecessary repairs are reduced considerably. This maintenance strategy not only focuses on fault detection but also monitors the degradation of the equipment and helps in failure prediction. Therefore, condition-based maintenance identifies and solves problems before any damage takes place. To assess the health of a system in condition maintenance system, different methods such as vibration monitoring, acoustic analysis, thermography, tribology, visual inspections, etc. are used. A small description of three popular techniques is mentioned below:

**1. Vibration Monitoring**

It is used to detect system malfunction based on measured vibration signals. System malfunction can be caused by misalignment, unbalance, resonance, loosened assemblies, turbulence, etc. Sensors are used to detect system malfunction. The sensitivity of sensors used for parameters such as amplitude, velocity, and acceleration vary with the frequency of vibration. Generally, for low-frequency signals, amplitude sensors are used, for middle ranges, velocity sensors are used, and accelerometers are used for higher frequencies.

**2. Thermography**

Thermography uses instruments to measure absolute or relative temperatures of key parts of the system. When a certain part of the system reaches temperatures beyond a certain point, the abnormal temperatures are taken as alarm signals of developing problems (Tsang, 1995). There are two types of equipment used in this technology. Thermometers and thermocouples are

popular ways to measure temperature of materials. The non-contact method uses infrared sensors and infrared imaging to capture thermal data.

**3. Tribology**

It is also called Lubricating Oil Analysis or Oil-based monitoring in condition-based maintenance. In this method, the condition of both the lubricant and the internal surfaces in contact with the lubricant is monitored at regular intervals. When oil reaches an alarming state, it is replaced to maintain and improve the system operation. The typical oil analysis is done to check the presence of contamination that can be internally generated, externally generated, water/moisture based, or from by-products from the chemical breakdown of lubricants. One of the major limitations of this method is expensive equipment and the accuracy and testing of oil samples.

### 2.4.4 Predetermined maintenance

Predictive maintenance (PdM) aims to predict failures before they happen so maintenance can occur at just the right time. PdM uses data from machine sensors and smart technology to alert the maintenance team when a piece of equipment is at risk of failing. For example, a sensor may use vibration analysis to alert the maintenance team that a piece of equipment is at risk of failing, at which point it will be taken offline, inspected, and repaired accordingly (Olesen and Shaker,2020).

### 2.4.5 Total Productive Maintenance

Oakley,(2021) discussion been held on direct process improvements using lean methods valuable in reducing waste that is a direct result of manufacturing practices. Total Productive Maintenance (TPM), however, focuses on continuous improvements based on reducing wastes related to machines and tooling used in manufacturing processes through a highly effective and efficient maintenance program. 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.

Total Productive Maintenance (TPM) is a methodology to form a corporate culture focus on maximizing the efficiency of overall production system through cross-functional section. TPM can be described as a plant improvement methodology which enables continuous and rapid improvement of the manufacturing process through the use of employee involvement, employee

empowerment and closed-loop measurement of results. It is a production driven improvement methodology that is designed to optimize equipment's reliability and ensure efficient management of plant assets. TPM also aims on building up a corporate culture that thoroughly pursues production systems efficiency improvement and Overall Equipment Efficiency (OEE). From both definition, it can be seen that they both describes a synergistic relationship among all organizational functions, but particularly between production and maintenance, for continuous improvement of product quality, operational efficiency, capacity assurance, safety and enhancement of the people who work within the company. It emphasizes maximizing Overall Equipment Effectiveness (OEE) through employee involvement. TPM activities involved all employees, starting from top management till ground floor operators. TPM program is marked to increase production while at the same time, increase employee morale and job satisfaction. In order to set up Total Productive Maintenance (TPM) framework, the understanding of it must be total. The goal of Total Productive Maintenance (TPM) is continuously improve all operational conditions, within a production system by motivating the daily understanding of all employees (Saman, 2012).

### 2.4.6 Reliability Centered Maintenance

(Singgih et al., 2019) Reliability Centered Maintenance (RCM) is a structured process used to identify failure management strategies and develop maintenance proactively for an asset and can also be used to find a number of better solutions in terms of maintenance so that assets or components can perform their functions. RCM is essentially a tool for doing fail management. From the failure potential, an analysis is carried out through RCM. From the management of failure, it will conclude how the maintenance should be done for a system or component to operate according to its function. By implementing the RCM method we will get several benefits, including:

a. Reducing maintenance costs directly by minimizing corrective maintenance and performing preventive maintenance effectively.
b. Availability of processes and efficiency improvements by reducing production losses caused by failure of components or systems.
c. Optimization of resources and organizations by promoting good collaboration between sections and providing quality training for RCM members(Auda,2019).

Reliability-centered maintenance (RCM) addresses the fact that failure is not always linear. RCM is a highly-involved process that seeks to analyze all the possible failure modes for each piece of equipment and customize a maintenance plan for each individual machine. The ultimate goal of RCM is to increase equipment availability or reliability (Singgih et al., 2019).

**2.5 Maintenance Strategy**

According to (Eindhoven and Version, 2021) maintenance strategy is convenient to think of equipment as a collection of interrelated parts & Maintenance operations consist largely (but not solely) in replacing parts of equipment. 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.

Maintenance strategy is a systematic approach to upkeep the facilities and equipment and it may vary from facility to facility. It involves identification, researching and execution of many repairs, replace and inspect decisions and is concerned with formulating the best life plan for each unit of the plant, in coordination with production and other functions concerned. It describes what events (e.g. failure, passing of time, condition) trigger what type of maintenance action (inspection, repair, or replacement) (Dhingra and Rama, 2013).

Maintenance strategies focused on prevention of the failure mode, where failure of equipment has its critical impact on desirable results (goals) or at a tolerable risk is a maintenance strategy focused on repair in case of failure occurs (Glatz and Pacaiova, 2015)

**2.6 The importance of a maintenance strategy**

Industry today is forced to increase production efficiency continuously in order to be competitive. The maintenance of production equipment is one important factor of this. A strategy (direction) is always followed, either consciously or unconsciously. When a strategy is not stated, only followed unconsciously, the result is often a reactive approach, which causes events and others to choose the direction. If a company does not work proactive to avoid failures or the consequences of failures, then the maintenance is operating on a run-to-failure strategy. If there is a well-developed and defined maintenance strategy which is known to everyone then new problems instead of old recurrence ones will be solved. If one is not, measurable time will be earned from develop and define a maintenance strategy, communicate it, and last focusing on the tactical choices for how to achieve it. Tactics are the actual activities needed to implement the strategy, which concerns the management of processes, people, and

physical asset infrastructure. The strategy are developed to create a direction of how to meet the objectives of maximum availability/reliability and gaining thorough knowledge in the technical systems with an easy to use and structured approach The objectives may appear to be intuitive, but not until they are written down can the importance of a proactive maintenance and reliability organization of a company and its assets be highlighted. The effectiveness of a company will always be sub-optimized unless the reliability and maintenance organization works with a proactive list of objectives. Thus, reliability and maintenance is more than a "fix it when it breaks" function. The objectives must be realized in accordance with safety and environmental regulations and also in a cost effective way. The integration of machines, men, methods and means into a well-designed strategy requires indispensable managerial capacity (Fedriksson and Larsson, 2012).

**2.7 Impact of Maintenance strategy**

Maintenance impact on business performance aspects such as productivity and profitability has increased. A day's output lost because of an unplanned stoppage will never be recovered without additional costs being incurred, e.g. overtime working. Customers who go elsewhere are lost business, sometimes forever. The importance of the maintenance function has increased, due to its role in keeping and improving availability, performance efficiency, quality products, on-time deliveries, environment and safety requirements, and total plant cost effectiveness at high levels. Disturbances in production processes due to maintenance and other causes reduce productivity, increase product cost and thereby reduce profitability. A failure in equipment or facilities not only results in loss of productivity, but also in a loss of timely services to customers, and may even lead to safety and environmental problems which destroy the company image. There is a need to show how maintenance could contribute to the overall business objective.

Traditionally, maintenance has been considered as a necessary evil, but in fact it is a profit centre rather than just unpredictable and unavoidable expense. The question of how maintenance could improve the company productivity and profitability need to be investigated further. Using effective maintenance policies, failures can be reduced to a minimum level. This could result in great savings. Therefore, maintenance is gaining more and more significance because of its role in the corporate long-term profitability. It has an impact on the production and its operational aspects such as capacity, quality, costs, environment and safety. But, because maintenance is considered a support function for production (which means that it has indirect effects on other

function) it is difficult to footprint its impacts. The maintenance performance perceived depends on the perspective applied: accountants think of maintenance in terms of costs, top management is only interested in budget performance, engineers focus on techniques, and production sees performance in terms of equipment availability and support responsiveness. Therefore, we can notice the lack of common language, which enable the different functions in the organization understand each other. For example, top management wants to have technical suggestions interpreted in economic terms, which are meaningful to their way of handling company matters. For overcoming this obstacle, one should not only translate the maintenance problem into economic measures, but also link it to the capital return and cost-revenue models of economy. Therefore, it is important to find the relationship between the maintenance performance and its impact on the corporate profitability (Alsyouf, 2007).

**2.8 Production bottleneck relative to maintenance**

Bottleneck problems from time-to-time slow-down and occasionally stop the entire manufacturing processes thereby limiting the manufacturing capacity. Asserted that all manufacturing systems are constrained by one or more bottleneck problems signifying that irrespective of how well a manufacturing system is designed it cannot be bottleneck-free including the digital manufacturing system or the industry 4.0 revolution. However, a manufacturing asset becomes a constraint on account of variable factors that influence the performance of the asset. Variables constituting bottleneck problems in the manufacturing environment are enormous and therefore compound the improvement decisions occasioned by a lack of direction from where to start addressing the problem. Hence, the challenge is how to identify the principal variables among the numerous variables causing the problem to sharpen process improvement focus and minimize manufacturing losses. And argued that any element of production can turn into a bottleneck by causing congestion, slow down or stop the manufacturing process. According to bottlenecks are inevitable when there are differences in job arrival and processing rates. The consequence of bottleneck problem on manufacturing system is loss of economic value because it defines the volume of the manufacturing outputs. Improving the bottleneck problems will enhance the overall manufacturing system. However, process improvement can only be achieved through bottleneck detection and identification, formulated a model to detect and identify the bottleneck problem in a manufacturing system based on the active duration for which a machine can run without interruption. This approach does not take

into account identification of the variable factor makes the manufacturing asset to become a bottleneck in the manufacturing process. In our opinion, a system bottleneck can be estimated as: (Onbali et al., 2021).

$$\text{System bottle} = \frac{Actual\ out\ capacity}{Install\ capacity} \text{x}100\% \quad (2.1)$$

**2.9 Maintenance management**

Salonen,(2009) gives the following generic expression for the maintenance objective: "...to achieve the agreed plant operating pattern, availability and product quality within the accepted plant condition (for longevity) and safety standards, and at minimum resource cost." claim that maintenance management must align with business activities at strategic, tactical, and operational levels. Lu et al.; 2020, 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.

**2.10 Maintenance cost**

Maintenance cost or maintenance related costs in general are usually divided into direct and indirect cost without putting maintenance savings and profit into consideration (Al-Najjar & Alsyouf, 2004). Direct and indirect costs according include cost that are connected with in-house and outhouse (outsourcing) maintenance activities. (Al- Najjar & Alsyouf, 2004) Further refer to direct maintenance costs as costs associated directly to the maintenance activities, which include the internal costs that are required to carry out the maintenance functions e.g. labor, tools, spare parts, training etc. and other maintenance expenses that are directly related. Indirect costs on the other hand includes all costs that are indirectly related or associated with maintenance, which can be attributed to issues like profit loss due to production losses during planned and unplanned stoppages, customer losses, reputation and consequently loss of market share as a result of maintenance related factors (Andrew & Moss, 2002). In addition, indirect maintenance costs includes performance inefficiency costs due to short stoppages and reduced speed, poor quality cost due to maintenance deficiency, idle fixed cost resources e.g. idle machine and idle worker costs during breakdowns, delivery delays

penalty cost as a result of unplanned down time, assurance claim from dissatisfied customers as a result of maintenance related poor quality.

**2.11 Implementation of six-sigma for maintenance strategy**

The Six Sigma method begins by recognizing critical elements of quality (critical to quality) of a process to provide suggestions on improvements related to defects that arise. Six Sigma has measurable improvement steps that will result in costs reduction and increased customer satisfaction to maintain the sustainability of a company as a whole (Trimarjoko, 2020).

This method follows a conductive five-step necessary to obtain reliable results, contracted in the acronym DMAIC for: Define, Measure, Analyze, Improve or Innovate and Check. The DMAIC approach of Six Sigma is with his toolbox as a filter to pass from a complex problem with many uncontrolled variables to a situation where quality is controlled. It is as follows:

**Define:** This phase helps clarify the issues of the project, to identify customer expectations, to set goals and designated project stakeholders. In this first step, it is necessary to focus on the process that generates the product or service and the map in order to be familiar;

**Measure:** This is a step of collecting data on measurable parameters of the process. The objective is to determine what is able to provide the process in question namely its sigma. During this stage, it is important to focus on critical parameters for the quality, that is, those whose influence on the result is the largest;

**Analyze:** Data obtained during the previous step are analyzed to calculate performance gaps, that is to say the differences between what is done every day and what can be achieved. We must then study the origins of the variability of the process and determine the root cause. At this stage, improvement solutions to remove the root causes of process variability concerned are proposed to meet objectives;

**Innovation:** The solutions to the dysfunctions proposed are validated by the project team and the ability of the optimized process is evaluated to ensure their impact. Finally, an action plan detailing the implementation of chosen solutions must be developed to best manage the changes induced by the solutions implemented.

**Check:** This last step is to control the process to ensure that the problem is solved and stay in quality level achieved.

During this step, we must maintain the benefits gained by standardizing the process. Finally, the financial statement is prepared in order to quantify the made gains. DMAICS means the DMAIC

approach to which is added a step for Standardization, designed to sustain the actions and solutions implemented in the first five steps.

### 2.12 Linear programming

Linear programming:- mathematical modeling technique in which a linear function is maximized or minimized when subjected to various constraints. This technique has been useful for guiding quantitative decisions in business planning, in industrial engineering, and—to a lesser extent—in the social and physical sciences. In Mathematics, linear programming is a method of optimising operations with some constraints. The main objective of linear programming is to maximize or minimize the numerical value. It consists of linear functions which are subjected to the constraints in the form of linear equations or in the form of inequalities. Linear programming is considered an important technique that is used to find the optimum resource utilization. The term linear programming consists of two words as linear and programming. The word linear defines the relationship between multiple variables with degree one. The word programming defines the process of selecting the best solution from various alternatives.

Linear Programming can also be used for verification and checking mechanism to ascertain the accuracy and the reliability of the decisions which are taken solely on the basis of manager's experience without the aid of a mathematical model (Solaja et al.,2020). It is useful in the allocation of scarce resources like materials, machine, man and time.

### 2.13 Maintenance management framework

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

Based on the Research report of (Keat and Ya'akob 2021), maintenance management framework defined aging and aging equipment as "aging is not about how old an equipment is, it is about its condition, and how that is changing over time. All types of equipment can be susceptible to aging mechanisms. (Alaswad and Xiang 2017), the significance of deterioration and damage related to potential effect on equipment's functionality, availability, reliability, and safety." The issue of aging plant leading to an increased risk of containment and other failures due to plant and equipment deterioration demonstrates the significant extent and impact of aging plant related failures on safety, environmental, and business performance (Monrose & Tota-Maharaj, 2018).

According to ( Keat et al., 2021), The seven subject groups and related subject elements are shown in Figure 2,.7, with each element further described and defined in subsequent sections of the document. The subject groups are: 1. Business Requirements 2. Maintenance Strategy Management 3. Maintenance management 4. Maintenance execution 5. Deliverables 6. Continual improvement 7. Allocation of resources.

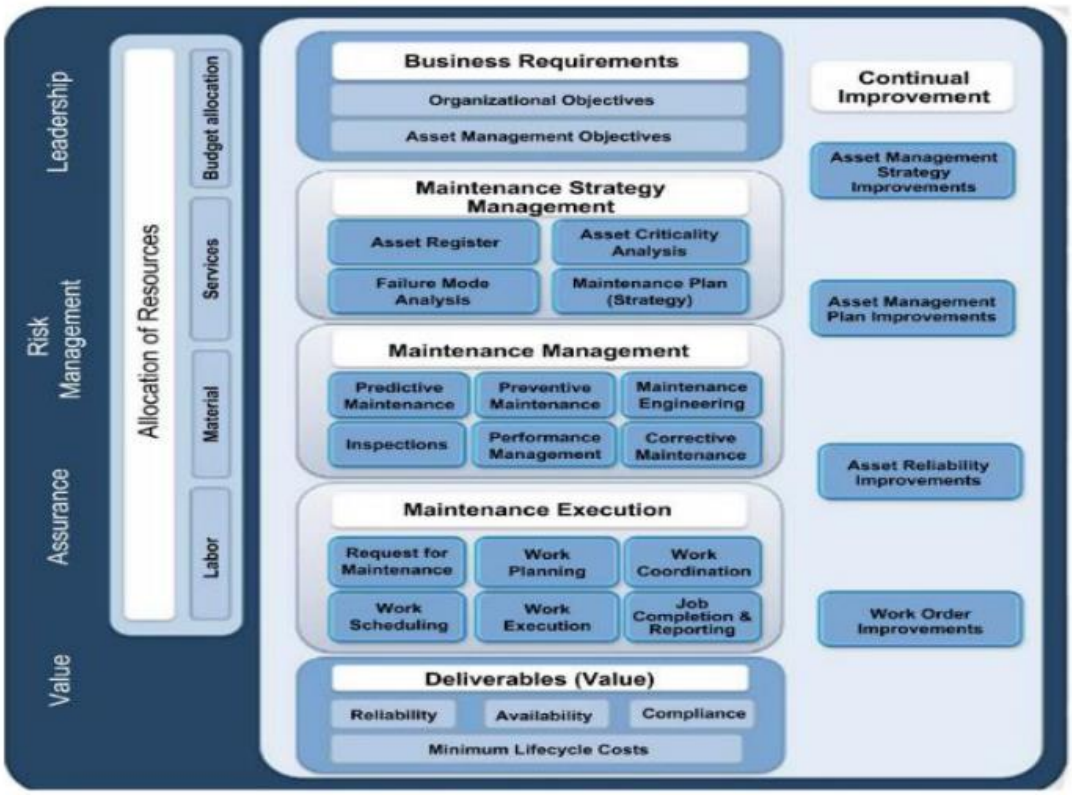



Figure 2.1 The maintenance management framework (Keat and Ya'akob, 2021)

While the diagram shows generally how the maintenance management subject groups fit in relation to each other and to the objectives of the organizational business plan, there is no one common workflow for maintenance management. The workflow depends uniquely on the organization and its environment(Er-ratby & Mabrouki, 2018).Maintenance can be managed totally internally, partially internally or completely outsourced. The application of the Maintenance management Framework can therefore vary according to organizational specific circumstances (Adesta and Prabowo 2018).

Table 2.1: Steps of Maintenance Management Framework (Adesta and Prabowo 2018)

| Subject Group | Subject Element | Subject Artefacts / Inclusions |
|---|---|---|
| 1. **Business and Organization Context** | 1.1. Requirements and Expectations | • AM Policy, Strategy and Plans. Commitments to comply. Desire to be a leader, pack, laggard; cutting edge or conservative… |
| | 1.2. Enablers and Constraints | • Budget, available technology, policy, willingness to invest, management style<br>• Identification methodologies<br>• Corporate business risk assessment |
| | 1.3. Management and Operational Frameworks | • Broad management concepts implemented at the organization level and having impacts on maintenance<br>• Lean manufacturing, JIT, Quality Management, Safety Management, Risk and Loss Management |
| | 1.4. Strategic Maintenance Plan | • Assessment, identify opportunity, improvement plans, define structure to be used. |
| 2. **Program Management** | 2.1. Maintenance Requirements | • Business requirements<br>• Stakeholder requirements<br>• Long Range and short term |
| | 2.2. Organizational Structure | • Autonomous Maintenance / TPM / Operator Care, Operator performed maintenance, Operator driven Reliability,<br>• centralized vs. decentralized vs. hybrid maintenance organization<br>• plant vs. mobile |
| | 2.3. Maintenance Program Models | Structure or "Model" used to organize maintenance approach.<br>Influenced by Organizations overall management concepts (1.3)<br>• Maintenance Framework "references"<br>• "Uptime", "SAMI" GFMAM, PEMAC, internal corporate developed |
| | 2.4. Maintenance Budgeting and Cost Control | • budgeting practices<br>• Stewardship process |
| | 2.5. Asset Identification and Hierarchy structure | Up Front decision processes about the assets to be managed and Hierarch structure<br>• What is managed at the asset level vs. the hierarchy location level<br>• Location hierarchy structure<br>• Hierarchy structure, logical vs. physical structure, depth of Hierarchy,<br>• Asset hierarchy structure<br>• Asset components vs asset parts definition<br>• nomenclature / taxonomy, master data requirements |
| | 2.6. Asset Criticality Analysis | • Criticality criteria<br>• Criticality assessment methodologies |
| | 2.7. Program Measurement / KPIs | • Self-Assessments<br>• Benchmarking |
| | 2.8. Change Management | • People side of change |
| | | • Methodologies |
| | 2.9. Outsourcing | • Scoping,<br>• Justification reasons for…,<br>• Service level agreements<br>• Management requirements, |
| 3. **Asset Strategy Management** | 3.1. Asset Maintenance Plans | Asset or Asset Grouping maintenance<br>• Asset classification (ISO 14224)<br>• Basic care plans<br>• Standard Job Plans<br>• Tactics determination processes<br>• Long rang and short term asset plans |
| | 3.2. Asset Strategy Performance Measurement & Optimisation | • Asset Availability, utilization, reliability,<br>• Cost of capacity |

| | | |
|---|---|---|
| **4. Tools and Tactics** | 4.1. Reliability Centered Maintenance | • Keywords "RCM" & "FMEA" |
| | 4.2. Preventive Maintenance Optimization | • Methodology<br>• Application experience |
| | 4.3. 5S/Housekeeping | • Methodology<br>• Application experience |
| | 4.4. Preventive Maintenance | • Keywords "Time-Based Maintenance", "Scheduled Maintenance" & "Meter-Based Maintenance" |
| | 4.5. Detective Maintenance | • Keywords "Fault-finding", "Inspections" & "Hidden Failures" |
| | 4.6. Condition Monitoring | • Keywords "Predictive maintenance" & "Condition-Based Maintenance"<br>• Condition Monitoring Tools & Technologies<br>• Mechanical Integrity Programs<br>• Structural Integrity Programs<br>• Risk-Based Inspections |
| | 4.7. Operator Performed Maintenance | Operator Care, Operator performed maintenance, Operator driven Reliability |
| | 4.8. Precision Maintenance Techniques | Development<br>Implementation |
| **5. Maintenance & Reliability Engineering** | 5.1. Statistical Analysis / Analytical Methods | • Keywords "Weibull Analysis", "Simulation" &"Monte Carlo Analysis" |
| | 5.2. Reliability Modelling | • Keywords "Reliability Block-Modelling, |
| | 5.3. Failure Analysis | • Processes, practices, controls<br>• Formal methods, facilitation, Apollo, PROACT, Kepner-Tregoe, TapRoot and others.<br>• Keywords "RCA", "RCFA", "NDT", "NDE", etc. |
| | 5.4. Critical Spares and Redundancy Analysis | • Processes, practices, controls<br>• Assessment, methodology |
| | 5.5. Reliability Sustainment | • Criticality, RCM, RCA/RCFA, RBM, ODR, PM Programs |
| | 5.6. Reliability Performance Measurement | • Keywords "OEE", "MTBF/MTTR", "Uptime", "Availability", etc. |

| | | |
|---|---|---|
| **6. Work Management** | 6.1. Work Identification | • Processes, practices, controls |
| | 6.2. Work Planning | • Processes, practices, controls Includes planning of labour, parts, materials, tools, contractors, etc. |
| | 6.3. Work Scheduling and Coordination | • Processes, practices, controls |
| | 6.4. Work Execution and Closeout | • Processes, practices, controls Includes LOTO /COHE<br>• Work completion information requirements<br>• Roles and responsibilities |
| | 6.5. Feedback and Analysis | • Processes, practices, controls |
| | 6.6. Backlog management | • Processes, practices, controls<br>• Use of Priority and Criticality, Backlog review, Feedback to Originators |

| | | |
|---|---|---|
| | 6.6. Backlog management | • Processes, practices, controls<br>• Use of Priority and Criticality, Backlog review, Feedback to Originators |
| | 6.7. Shutdowns and Turnarounds | • Processes, practices, controls<br>• Techniques for planning, scheduling, scope management, work execution, contractor management<br>• Includes special requirements not covered in above |
| | 6.8. Management of Change | • Management of Physical or process related changes<br>• Documentation, procedures, practices, process diagrams, manuals, drawings, parts information, configuration, version control.<br>• Documentation of physical changes |
| **7. Human Resource Management** | 7.1. Education, Training and Development | • apprenticeships, specialties, pay for skill, Succession planning, personal development, professional development, professional association.<br>• Succession Planning |
| | 7.2. Skills and Qualification Management | • Keywords "Skills Matrix ", etc. |
| | 7.3. Roles and Responsibilities | • Process and RACI charts<br>• On-boarding practices – new hire or transfer or promotion<br>• Administrative Management of Change |
| | 7.4. Contractor Management | • Contract management, scope definition, type of contract, performance expectations, win-win |
| **8. Material Resource Management** | 8.1. Work Management Integration | • Integration of materials and work management processes, WO kitting, staging and delivery |
| | 8.2. Inventory Management | • Processes, practices, controls<br>• Min/Max control<br>• Obsolescence management |
| | 8.3. Lubricants Management | • Processes, practices, controls |
| | 8.4. Spares Rebuild and Refurbishment | • Processes, practices, controls<br>• Restore vs replace<br>• Business case |
| | 8.5. Tools and Equipment Management | • Processes, practices, controls<br>• Requirements definition, tool crib, calibration, storage and maintenance |
| **9. Information Management** | 9.1. Information Systems | • Keywords "CMMS", "EAM", "ERP", "DCS", "SCADA"<br>• Specialized T/A Shutdown management tools (Primavera) |
| | 9.2. Standards and Specification | • HS&E requirements<br>• Work specifications<br>• Standard work practices |

| | | |
|---|---|---|
| | 9.3. Master Data | • Management processes and practices<br>• master data requirements,<br>• Master dates records structure<br>• Can include management of master data for critical components and inventory items |
| | 9.4. Document Management | • Drawings, Vendor Information<br>• (anything not covered in above) |
| | 9.5. Records Management | • Maintenance activity completion records<br>• Quality records<br>• Proof of compliance<br>• Calibration documents |
| **10. Continuous Improvement** | 10.1. Metrics / KPIs | • Definitions/Calculations<br>• Books, benchmarks, Hoshin Kanri, Dashboard and KPI management systems |
| | 10.2. Benchmarking | • Methods; Benchmark studies, peer group comparisons, industrial visits<br>• Application experiences |
| | 10.3. Maintenance Management Improvements | • KPIs vs. targets, audits, learning processes (conferences, training, certifications), project management, re-engineering, process improvement, strategy and plan improvements |
| | 10.4. Maintenance Practices Improvements | • Reliability engineering, Life Cycle Cost Analysis, applying RCM / FMEA<br>• Leveraging RCM outputs in support infrastructure |
| | 10.5. Asset Reliability Improvements | • Lessons learned to engineering and operators, RCM outputs, RCFA, PMO |

## 2.14 Research gap

The production of sugar declined from time to time due to maintenance problem which provided machineries down time, which highly affect productivity. most researches had done on the problem associated to maintenance and in order to solve those maintenance problems by focusing on different maintenance approaches. But there was no report on using implementation of Minitab software to solve maintenance problem and no much previous works have investigated the optimization of down time using Minitab software by generating multiple regression models and predicted or optimized downtimes not set at Metahara Sugar Factory.

# CHAPTER-3

# METHODOLOGY

## 3.1. Introduction

This study was based on case study research method. A case study for this research empower the researcher to collect data on the operations or cane crushing campaign of the last consequentive five years from 2017/18 to 2021/22 with in Metahara Sugar Factory and being an employee at the company; the researcher spent an extended period of time on site and interact regularly with the workers and departments that were being studied. The empirical study consists of the survey (questionnaires) at Metahara Sugar Factory. The survey enabled the researcher to make direct contact with the lead technician, supervisors, seniors, coordinators, management team, team leaders, team members and maintenance experts within the different departments to establish their expectations of maintenance management systems;observe the activities that support the assessment of the maintenance management system.

In this study both primary and secondary data sources were used. Primary data source includes raw, original, non-interpreted and unevaluated data. The secondary data sources were technical documents and annual reports that help to cross check the official information and to get details concerning the study. Discussion, interview and questionnaires were techniques that were used for gathering primary information and relevant data for the study.

## 3.2. Research Method

This study used two kinds of sources to collect information, primary and secondary sources. Primary sources focused on information which helped to had the entire understanding of the study through different techniques such as interviews, questionnaires, & discussions. Whereas secondary sources of information related with the study to have detail understanding with the supportive documents and reports.

To make effective the collection used two methods, quantitative and qualitative method. Quantitative implies that the way of collections which can be described, counted, and measured in certain amount. Thus, the result expressed in number and formulated. But qualitative method has been a different way of expression in reverse that can’t be expressed in figure.

### 3.3. Data Collection Method

The methodology followed to approach with reliable results, collecting data on the current maintenance system, maintenance organization and production constraints. The downtime, critical machinery breakage, lack of technician's training, unavailability of machineries spare parts were believed to indicate the appropriate maintenance functions various survey methods used to assess the current situation of the company.

#### 3.3.1. Primary Data

Primary data defined as data collected by a program of observation qualitative and quantitative method either separately or in combination to meet the specific objective of the research.

**a. Physical observation**

Physical observations carried out to see the maintenance system on some critical equipment or working stations.

**b. Survey questionnaires**

For the purpose this thesis, the following data collection methods were used. Different department managers and respective employees of the company have been interviewed regarding the impact of maintenance on the machine downtime, nature of work, maintaining their machines, how much maintenance workers exist, the techniques of maintenance they practice, and other working conditions. Depending on the company's data, the total downtimes failure was calculated. Moreover, based on this data given, the existing maintenance system of the company evaluated. The survey questionnaires for assessing the maintenance system in the company were designed.

**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 (Huang, 2020). The purpose of sampling in quantitative research was to draw inferences about the group from which the sample selected, whereas in qualitative research 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 was typical

of the group and hence would be provided insight into the group. Due to the above reasons, suitable for study.

The questionnaires prepared by using Taro Yamane formula to determine the sample size for data collection from mechanical, electrical and instrument, production and boiler maintenance teams staffs about maintenance issues.

$$n = \frac{N}{1+Ne2}$$ where N=population size = 70

$$n = \frac{70}{1+70*0.052}$$ n = sample size

n = 60

e = error (0.05) reliability level 95%

Level of precision always set the value of 0.05.

The questionnaires were prepared for lead technicians, supervisors, seniors, coordinators, management teams and workers (mechanics and operators) department. Based on the above calculation questionnaires were distributed for 60 employers, then collected and analyzed based on four major maintenance teams. The questionnaires answered accordingly to the priority of concern by using predetermined sets of questions with predefined ranges of answers so as to avoid any conflicting series of response.

Table 3.1 Participants for questionnaire data collection with their respective positions

| S.no | Departments/team | Position | Quantity |
|---|---|---|---|
| 1 | Mechanical maintenance team | Mechanics, lead technicians, supervisors, seniors and team leader | 25 |
| 2 | Electrical and instrument maintenance team | Electricians, lead technicians, supervisors, seniors and team leader | 10 |
| 3 | Boiler and power generation team | operators, lead technicians, supervisors, seniors and team leader | 15 |
| 4 | Mechanical and fabrication workshops | Mechanics, lead technicians, supervisors, seniors and team leader | 10 |

The questionnaire used in the study consists of seven main parts and 43 main questions comprising a total of 3 pages. The questionnaires contained five types of answers i.e. Strongly agree, agree, neutral, disagree and strongly disagree.

According to the table of reliability and validity were checked, and the value of Cronbach's Alpha was calculated as follow $\alpha = \frac{k}{k-1}(1-\frac{\Sigma Si2}{Sy2})$,

Where, Si2= Sum individual square sum of variance

Sy2 = total variance square

k = number of questions

$\alpha = \frac{20}{20-1}(1-\frac{24.98}{114.45})$

**= 0.82** which is the range of good. So, reliability level is good.

Table 3.2 Reliability Analysis and Checking

**Case Processing Summary**

| | N | % |
|---|---|---|
| Valid | 20 | 100.0 |
| Case Exclude | 0 | 0 |
| Total | 20 | 100.0 |

**Reliability Statistics**

| Cronbach's Alpha | N of Items |
|---|---|
| 0.82 | 43 |

### 3.3.2 Secondary Data

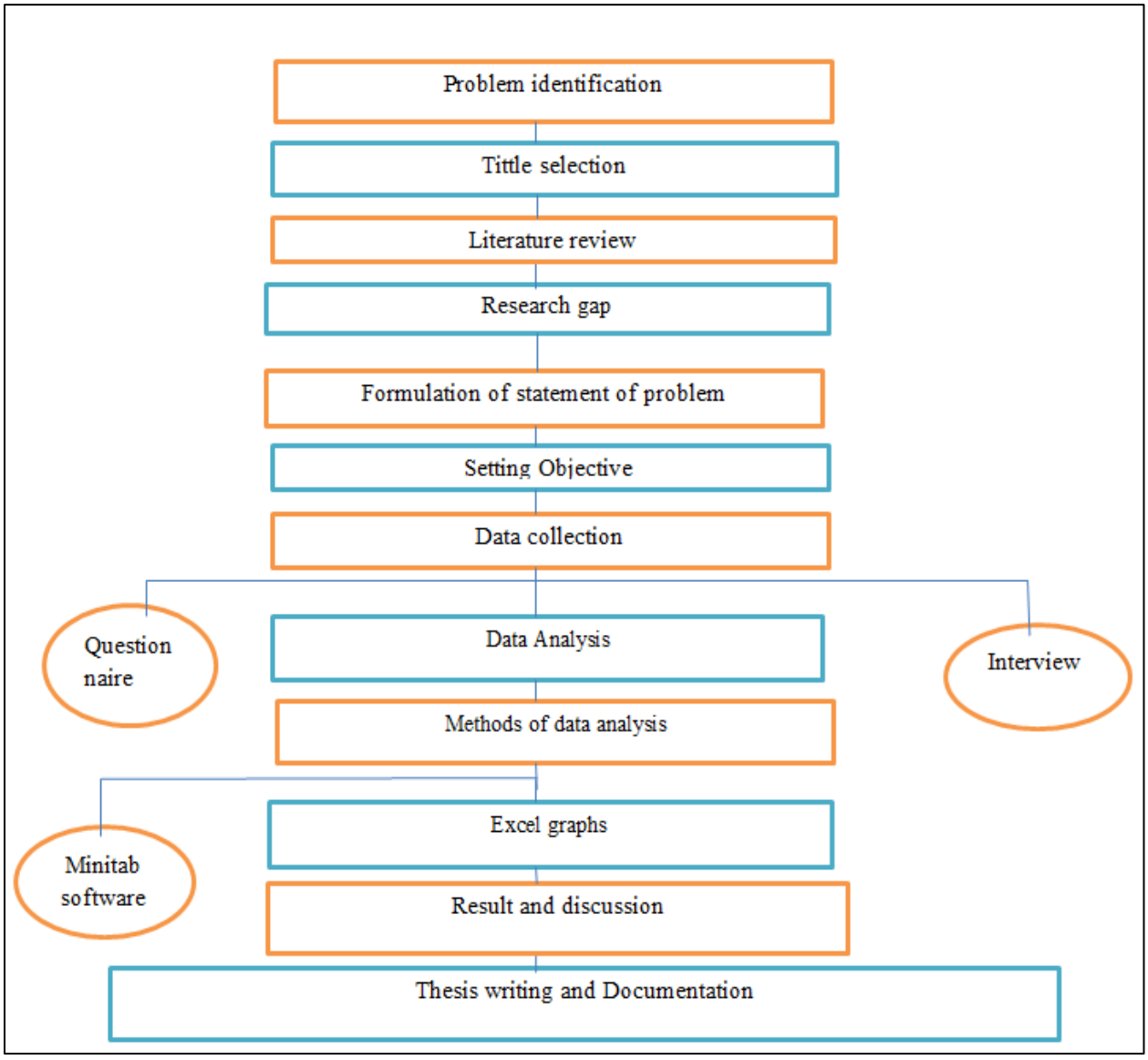
Secondary data was the information that the organization had. This information was valuable to this research to allowed seeing the relationship existing currently in Metahara Sugar Factory.

**Document retrieval**

During document analysis the researcher was gone through company manual, maintenance organization chart, monthly and annual performance reports and others relevant documents and formats of the company.

### 3.5. Data Analysis

In this thesis, study data were collected by questionnaires and current factory data recorded on the last five years from 2017/18 to 2021/22. Then the collected data were analyzed and interpreted by Statistical Package for Social Sciences (SPSS) software, Microsoft Excel and Minitab software which used to gather necessary solution for the problem.




3.1 Frame work of the methodology

# CHAPTER - 4

# DATA ANALYSIS AND DISCUSSION

### 4.1 Introduction

The analysis of this thesis work started from studying current production performance and productivity of the case study Metahara Sugar Factory sugar production. Since reliable quantitative metric which was used in most of manufacturing systems for controlling and monitoring the productivity effect were chosen as tool. Metahara sugar factory was high productivity problem due to machineries down time at cane handlings, millings, boiler, process house (clarification, Evaporation, Vacuum and centrifugal) plants.

## 4.2 Quantitative Data

### 4.2.1 Analysis of data from questionnaires

### 4.2.2 Educational background

The Figure 4.1 and Table 4.1 described that the organization had educated employers, with 38% of respondents held a diploma, 59% first degree and 3% of them were masters' degree. These data showed that there were professional workers in the factory. By properly and effectively utilizing and allocating those according to their qualification and a number of master's degree could be added to enhance the factory productivity.

**Table 4.1** Educational back ground of respondent

| Qualification | Number of employ | Percent of employ |
|---|---|---|
| Diploma | 22 | 38 |
| Degree | 35 | 59 |
| Master | 2 | 3 |

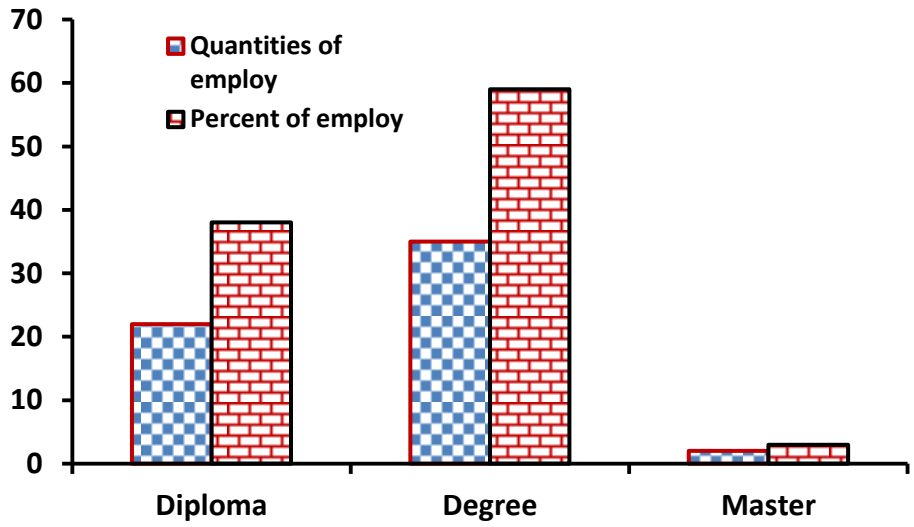



Figure 4.1 Education background of respondent

### 4.2.3 Experience of respondent

The Figure 4.2 and Table 4.2 showed that in the organization the experience of the employers were stated as follow. The employers those had a year of experience from 0-5 years were 20%, 6-10 years were 27%, 11-15 years were 32%, 16-20 years were 15% and above 21 years were 6%. These data showed that the organization had experienced employers. This more likely to promoted the organization as great place to work and increased the productivity.

**Table 4.2** Experience of respondent

| Year(yrs.) | Quantities of employ | Percent of employ |
|---|---|---|
| 0-5 yrs. | 12 | 20 |
| 6-10 yrs. | 16 | 27 |
| 11-15 yrs. | 19 | 32 |
| 16-20yrs. | 9 | 15 |
| above 21 yrs. | 4 | 6 |

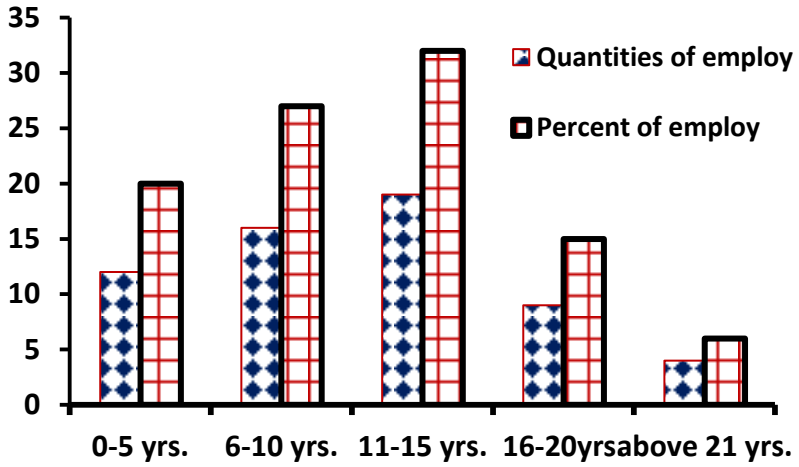



**Figure 4.2** Experience of respondent

### 4.2.4 Maintenance team

The Table 4.3 expressed that the respondents of the maintenance team in the organization. Under this point each question was discussed as follows. The respondents who responded the question asked on high machinery failure in specific plant were as follows; 56.6% strongly agreed, 33.33% agreed, 3.33% neutral, 6.66% disagreed and 0% strongly disagreed. This data showed, there was high machinery failure in specific plant which could decrease productivity which needs detailed investigation. The next question was on the skill of maintenance staff, which the respondents' reactions were; 20% strongly agreed, 50% agreed, 15% neutral, 7% disagreed and 3.33% strongly disagreed. From the analyzed data the company had skilled staff. The next question was on the workers continuously training were given, on this point the respondents responded as follow; 1.66% strongly agreed, 3.33% agreed, 15% neutral, 51.66% disagreed, and 28.33% strongly disagreed. From the described data the training was not given. The company should be given the training continuously based on analyzing their gaps. This provided the employers more skilled.

The next question was the support staffs actively collaborated with maintenance technician were responded by respondent; 21.66% strongly agreed, 45% agreed, 8.33% neutral, 18.33% disagreed and 6.66% strongly disagreed. The majority of respondents responded showed that the staffs were actively collaborated to support the technicians.

**Table 4.3:** Frequency table for Maintenance team

| **Maintenance team** | | **5** | **4** | **3** | **2** | **1** |
|---|---|---|---|---|---|---|
| There is high machinery failure in specific plant. | Freq. | 34 | 20 | 2 | 4 | 0 |
| | % | 56.6 | 33.33 | 3.33 | 6.66 | 0 |
| Skill of Maintenance staff is well sufficient. | Freq. | 12 | 30 | 9 | 7 | 2 |
| | % | 20 | 50 | 15 | 11.66 | 3.33 |
| The workers are continuously given training. | Freq. | 1 | 2 | 9 | 31 | 17 |
| | % | 1.66 | 3.33 | 15 | 51.66 | 28.33 |
| The support staffs actively collaborate with maintenance technicians | Freq. | 13 | 27 | 5 | 11 | 4 |
| | % | 21.66 | 45 | 8.33 | 18.33 | 6.66 |
| New employees were provided with the necessary training on maintenance before assigning to position. | Freq. | 9 | 31 | 8 | 7 | 5 |
| | % | 15 | 51.66 | 13.33 | 11.66 | 8.33 |
| On time resources were sufficiently allocated for maintenance. | Freq. | 1 | 8 | 5 | 26 | 20 |
| | % | 1.66 | 13.33 | 8.33 | 43.33 | 33.33 |

**Note: 5 = strongly agree, 4 = Agree, 3 = Neutral, 2 = Disagree, 1 = strongly disagree**

The other question was for the workers continuously training were given, on this point the respondents were responded as follow; 1.66% strongly agreed, 3.33% agreed, 15% neutral, 51.66% disagreed, and 28.33% strongly disagreed. From the described data the training for workers were not given for the employers continuously. The company should be given the training for the workers continuously based on analyzing their gaps. This provided the workers become skilled and updated themselves. From doing this the company production capacity become increased.

The other question was for new employees were provided with the necessary training on maintenance before assigning to position, on this point the respondents were responded as

follow; 15% strongly agreed, 51.66% were agreed, 13.33% neutral, 11.66% disagreed, and 8.33% strongly disagreed. From the described data most of the respondents were responded for new employees necessary training on maintenance before assigning to position were provided. So, it was best practices and should be progressed to had qualified and good leader to made the company productive more.

The next point was on time resources were sufficiently allocated for maintenance, were responded by respondent like this; 1.66% strongly agreed, 13.33% agreed, 8.33% neutral, 43.33% disagreed and 33.33% for the strongly disagreed. The majority of respondents responded showed on time resources were not sufficiently allocated for maintenance. This made the company not produced the planned or designed sugar.

**4.2.5 Machineries maintenance program**

Table 4.4 illustrated the machineries maintenance program as follow based on the provided questions. On the point, there was clear schedule for maintenance were responded by respondent as follow; 13.33% strongly agreed, 10% agreed, 11.66% for the neutral, 38.33% disagreed and 26.66% strongly disagreed. The majority of respondents responded show that there was no clear schedule for maintenance. The other question was there was shortage of spare parts for machineries. On this point the respondents responded as follow; 60 strongly agreed, 31.66% agreed, 3.33% neutral, 3.33% disagreed, and 1.66% e strongly disagreed. From the described data most of the respondents were responded there was shortage of spare parts for machineries. The other point was, there were bottleneck machineries in the plant, on this point the respondents responded as follow; 50% strongly agreed, 35% agreed, 6.66% neutral, 6.66% disagreed, and 1.66% strongly disagreed. From the described data most of the respondents responded there were bottleneck machineries in the plant. The next point was, there was a policy to reject frequently failed machines, on this point the respondents were responded as follow; 0% strongly agreed, 6.66% agreed, 15% neutral, 45% disagreed, and 33.33% strongly disagreed. From the described data most of the respondents responded there was no a policy to reject frequently failed machines. Therefore, a policy needed which rejected the frequent failure of machineries.

The other question was for there is clear maintenance work flow; on this point the respondents responded as follow; 5% strongly agreed, 25% agreed, 8.33% neutral, 33.33% disagreed, and 28.33% strongly disagreed. From the described data most of the respondents were responded for there was not clear maintenance work flow. The other question was shutdowns are planned for

major repairs in advance; on this point the respondents were responded as follow; 5% strongly agreed, 21.66% agreed, 10% neutral, 35% disagreed, and 28.33% strongly disagreed. From the described data most of the respondents were responded for shutdowns were no planned for major repairs in advance.

**Table 4.4:** Frequency for Machineries maintenance program

| **Machineries maintenance program** | | **5** | **4** | **3** | **2** | **1** |
|---|---|---|---|---|---|---|
| There is clear schedule for maintenance. | Freq. | 8 | 6 | 7 | 23 | 16 |
| | % | 13.33 | 10 | 11.66 | 38.33 | 26.66 |
| There are shortage of spare parts for machineries. | Freq. | 36 | 19 | 2 | 2 | 1 |
| | % | 60 | 31.66 | 3.33 | 3.33 | 1.66 |
| There are bottleneck machineries in the plant. | Freq. | 30 | 21 | 4 | 4 | 1 |
| | % | 50 | 35 | 6.66 | 6.66 | 1.66 |
| There is a method to follow frequently failed machines. | Freq. | 0 | 4 | 9 | 27 | 20 |
| | % | 0 | 6.66 | 15 | 45 | 33.33 |
| There is clear maintenance work flow. | Freq. | 3 | 15 | 5 | 20 | 17 |
| | % | 5 | 25 | 8.33 | 33.33 | 28.33 |
| Shutdowns are planned for major repairs in advance. | Freq. | 3 | 13 | 6 | 21 | 17 |
| | % | 5 | 21.66 | 10 | 35 | 28.33 |

### 4.2.6 Maintenance evaluation

The Table 4.5 described that the maintenance evaluation based on the questions stated below.

On the point, the sufficient evaluation mechanism for the performance maintenance exists. On this point the respondents were responded as follow; 5% strongly agreed, 20% agreed, 13.33% neutral, 36.66% disagreed, and 25% strongly disagreed.

**Table 4.5:** Frequency for maintenance Evaluation

| **Maintenance evaluation** | | **5** | **4** | **3** | **2** | **1** |
|---|---|---|---|---|---|---|
| Sufficient evaluation mechanism for the performance maintenance exists. | Freq. | 3 | 12 | 8 | 22 | 15 |
| | % | 5 | 20 | 13.33 | 36.66 | 25 |
| Maintenance key performance indicators are known | Freq. | 9 | 11 | 7 | 18 | 15 |
| | % | 15 | 18.33 | 11.66 | 30 | 25 |
| Equipment's maintained according to maintenance standard. | Freq. | 3 | 7 | 7 | 25 | 18 |
| | % | 5 | 11.66 | 11.66 | 41.66 | 30 |
| During and after maintenance the maintenance activities checked by supervisors. | Freq. | 18 | 31 | 8 | 2 | 1 |
| | % | 30 | 51.66 | 13.33 | 3.33 | 1.66 |
| Machineries spare parts were used as a standard. | Freq. | 9 | 26 | 7 | 12 | 6 |
| | % | 15 | 43.33 | 11.66 | 20 | 10 |
| The equipment is maintained within sufficient time when the equipment failed. | Freq. | 3 | 14 | 8 | 25 | 10 |
| | % | 5 | 23.33 | 13.33 | 41.66 | 16.66 |
| Technician regularly report actual working time, used material, and downtime on time. | Freq. | 7 | 12 | 9 | 21 | 11 |
| | % | 11.66 | 20 | 15 | 35 | 18.33 |

From the described data majority of the respondents responded there was no sufficient evaluation mechanism for the performance maintenance exists. The other point was, the maintenance key performance indicators were known, on this point the respondents were responded as follow; 15% strongly agreed, 18.33% agreed, 11.66% neutral, 30% disagreed, and 25% strongly disagreed. From the described data majority of the respondents responded there were no maintenance key performance indicators.

The other question was that equipment's maintained according to maintenance standard; on this point the respondents were responded as follow; 5% strongly agreed, 11.66% agreed, 11.66% were neutral, 41.66% disagreed, and 30% strongly disagreed. From the described data majority of the respondents responded there was no equipment's maintained according to maintenance standard.

The other point was, during and after maintenance the maintenance activities checked by supervisors; on this point the respondents responded as follow; 30% strongly agreed, 51.66% agreed, 13.33% neutral, 3.33% disagreed, and 1.66% strongly disagreed. From the described data majority of the respondents responded there were during and after maintenance the maintenance activities checked by supervisors. The other point was machineries spare parts were used as a standard; on this point the respondents were responded as follow; 15% strongly agreed, 43.33% agreed, 11.66% neutral, 20% disagreed, and 10% strongly disagreed. From the described data majority of the respondents responded there were machineries spare parts were used as a standard. The other question was, the equipment are maintained within sufficient time when the equipment failed; on this point the respondents responded as follow; 5% strongly agreed, 23.33% agreed, 13.33% neutral, 41.66% disagreed, and 16.66% strongly disagreed. From the described data most of the respondents were responded for the equipment's were not maintained within sufficient time when the equipment failed. The other question was, technician regularly report actual working time, used material, and downtime on time; on this point the respondents responded as follow; 11.66% strongly agreed, 20% agreed, 15% neutral, 35% disagreed, and 18.33% strongly disagreed. From the described data most of the respondents were responded for the equipment's were not maintained within sufficient time when the equipment failed.

### 4.2.7 Maintenance strategy

The table 4.6 described that the maintenance strategy based on the questions introduced below. On the point, there were clear maintenance strategy in the industry; on this point the respondents responded as follow; 16.67% strongly agreed, 16.67% agreed, 6.66% neutral, 38.33% disagreed, and 23.33% strongly disagreed. From the described data majority of the respondents responded there was no clear maintenance strategy in the industry. The other point was, the preventive maintenance program done according to schedule and program; on this point the respondents responded as follow; 6.67% strongly agreed, 18.33% agreed, 11.67% neutral, 40% disagreed, and 23.33% strongly disagreed.

From the described data majority of the respondents responded the preventive maintenance program was not done according to schedule and program. The other question was, the maintenance program periodically reviews preventive maintenances for accuracy and training needs; on this point the respondents were responded as follow; 3.33% strongly agreed, 15% agreed, 18.33% neutral, 40% disagreed, and 23.33% strongly disagreed. The other question was, the break down maintenance system highly implemented in the factory; on this point the respondents responded as follow; 41.67% strongly agreed, 33.33% agreed, 13.33% neutral, 8.33% disagreed, and 3.33% strongly disagreed. From the described data most of the respondents responded the break down maintenance system highly implemented in the factory. The other point was, the condition based maintenance system highly implemented in the factory; on this point the respondents responded as follow; 31.66% strongly agreed, 45% agreed, 10% neutral, 10% disagreed, and 3.33% strongly disagreed. From the described data most of the respondents the condition based maintenance system highly implemented in the factory. This provided high down times and decreased productivity. The other point was, the organization tried to prevent breakdowns and failures; on this point the respondents were responded as follow; 30% strongly agreed, 45% agreed, 13.33% neutral, 10% disagreed, and 1.66% strongly disagreed. From the described data most of the respondents the organization tried to prevent breakdowns and failures. This good and should be continued by facilitating the required other necessary things.

The other point was, the organization had a schedule for periodic preventive maintenance; on this point the respondents were responded as follow; 28.33% strongly agreed, 38.33% agreed, 6.67% neutral, 21.67% disagreed, and 5% strongly disagreed. From the described data majority of the respondents the organization had schedule for periodic preventive maintenance. The next point was, The organization has an inspection team to check the actual condition of equipment; on this point the respondents were responded as follow; 18.33% strongly agreed, 45% agreed, 13.33% neutral, 11.67% disagreed, and 11.67% strongly disagreed

**Table 4.6** Frequency for maintenance strategy

| **Maintenance strategy** | | **5** | **4** | **3** | **2** | **1** |
|---|---|---|---|---|---|---|
| There was clear maintenance strategy in the industry. | Freq. | 10 | 9 | 4 | 23 | 14 |
| | % | 16.67 | 15 | 6.67 | 38.33 | 23.33 |
| The preventive maintenance program done according to schedule and program. | Freq. | 4 | 11 | 7 | 24 | 14 |
| | % | 6.67 | 18.33 | 11.67 | 40 | 23.33 |
| The maintenance program periodically reviews preventive maintenances for accuracy and training needs. | Freq. | 2 | 9 | 11 | 24 | 14 |
| | % | 3.33 | 15 | 18.33 | 40 | 23.33 |
| The break down maintenance system highly implemented in the factory. | Freq. | 25 | 20 | 8 | 5 | 2 |
| | % | 41.67 | 33.33 | 13.33 | 8.33 | 3.33 |
| The condition based maintenance system highly implemented in the factory. | Freq. | 19 | 27 | 6 | 6 | 2 |
| | % | 31.66 | 45 | 10 | 10 | 3.33 |
| The organization tries to prevent breakdowns and failures. | Freq. | 18 | 27 | 8 | 6 | 1 |
| | % | 30 | 45 | 13.33 | 10 | 1.66 |
| The organization has a schedule for periodic preventive maintenance. | Freq. | 17 | 23 | 4 | 13 | 3 |
| | % | 28.33 | 38.33 | 6.67 | 21.67 | 5 |
| The organization has an inspection team to check the actual condition of equipment. | Freq. | 11 | 27 | 8 | 7 | 7 |
| | % | 18.33 | 45 | 13.33 | 11.67 | 11.67 |

From the described data majority of the respondents the organization had an inspection team to check the actual condition of equipment.

### 4.2.8 Production volume

The Table 4.7 illustrated that the production volume based the question stated under it. On the point that there were frequent machine downtimes; on this point the respondents responded as follow; 38.33% strongly agreed, 51.67% agreed, 5% neutral, 3.33% disagreed, and 1.67% strongly disagreed. From the described data majority of the respondents there were frequent machine downtimes. The next point was, the machine downtime minimizes planned production capacity; on this point the respondents were responded as follow; 46.66% strongly agreed, 43.33% agreed, 6.66% neutral, 1.67% disagreed, and 1.67% strongly disagreed.

**Table 4.7**: Frequency for production volume

| **Production volume** | | **5** | **4** | **3** | **2** | **1** |
|---|---|---|---|---|---|---|
| There is frequent machine downtime. | Freq. | 23 | 31 | 3 | 2 | 1 |
| | % | 38.33 | 51.67 | 5 | 3.33 | 1.67 |
| Machine downtime minimizes planned production capacity. | Freq. | 28 | 26 | 4 | 1 | 1 |
| | % | 46.67 | 43.33 | 6.66 | 1.67 | 1.67 |
| Employees are encouraged to apply better methods when doing work after learning new skills. | Freq. | 14 | 24 | 9 | 9 | 4 |
| | % | 23.33 | 40 | 15 | 15 | 6.67 |
| The production focuses on maintenance practice | Freq. | 13 | 29 | 6 | 7 | 5 |
| | % | 21.66 | 48.33 | 10 | 11.67 | 8.33 |
| Decline of production has a huge impact on the company. | Freq. | 36 | 17 | 3 | 2 | 2 |
| | % | 60 | 28.33 | 5 | 3.33 | 3.33 |
| The level of machine downtime affects total production time | Freq. | 32 | 19 | 4 | 4 | 1 |
| | % | 53.33 | 31.67 | 6.67 | 6.67 | 1.67 |

From the described data majority of the respondents on this point showed that reduced production capacity. For this reason, the organization should be avoided or minimized the down

times. The other point was, employees were encouraged to apply better methods when doing work after learning new skills; on this point the respondents were responded as follow; 23.33% strongly agreed, 40% agreed, 15% neutral, 15% disagreed, and 6.67% strongly disagreed. From the described data majority of the respondents on this point showed that was good. The other point was, the production focused on maintenance practice; on this point the respondents responded as follow; 21.66% strongly agreed, 48.33% agreed, 10% neutral, 11.67% disagreed, and 8.33% strongly disagreed. From the data described that could be concluded the majority of the respondents on this point expressed that the production focused on maintenance practices. The next point was, the decline of production had a huge impact on the company; on this point the respondents were responded as follow; 60% strongly agreed, 28.33% agreed, 5% neutral, 3.33% disagreed, and 3.33% strongly disagreed. The last question for this section was, the level of machine downtime affected total production time; the respondents were responded on this point as follow; 53.33% strongly agreed, 31.67% agreed, 6.67% neutral, 6.67% disagreed, and 1.67% strongly disagreed.

**4.2.9 Machineries or equipments down time**

From the Table 4.8 illustrated that the machineries or equipments down time based the questions were stated. The firs point was, there were high machineries down time in the factory; on this point the respondents were responded as follow; 50% strongly agreed, 33.33% agreed, 6.67% neutral, 6.67% disagreed, and 0% strongly disagreed. From the described data most of the respondents there were high machineries down time in the factory. The second point was, the productivity was highly affected by machineries down time; on this point the respondents responded as follow; 50% strongly agreed, 31.66% agreed, 10% neutral, 5% were disagreed, and 3.33% strongly disagreed. From the described figure the productivity affected by down times. The third point was, there were frequently failed machines in the factory; on this point the respondents responded as follow; 35% strongly agreed, 43.33% e agreed, 10% neutral, 11.67% were disagreed, and 0% strongly disagreed. From the described figure could be concluded that there were frequently failed machines in the factory which affected productivity.

The fourth point was, there were machines components which provided high down time in the factory; on this point the respondents responded as follow; 30% strongly agreed, 46.67% agreed, 13.33% neutral, 10% disagreed, and 0% strongly disagreed. From the described figure that there were machines components which provided high down time in the factory.

**Table 4.8:** Frequency for Machineries or equipments down time

| Machineries or equipments down time | | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|---|
| There are high machineries down time in the factory. | Freq. | 30 | 20 | 4 | 4 | 2 |
| | % | 50 | 33.33 | 6.67 | 6.67 | 3.33 |
| The productivity is highly affected by machineries down time. | Freq. | 30 | 19 | 6 | 3 | 2 |
| | % | 50 | 31.66 | 10 | 5 | 3.33 |
| There are frequently failed machines in the factory. | Freq. | 21 | 26 | 6 | 7 | 0 |
| | % | 35 | 43.33 | 10 | 11.67 | 0 |
| There are plants were machineries are highly failed. | Freq. | 17 | 27 | 7 | 6 | 3 |
| | % | 28.33 | 45 | 11.67 | 10 | 5 |
| There are machines components which provided high down time in the factory. | Freq. | 18 | 28 | 8 | 6 | 0 |
| | % | 30 | 46.67 | 13.33 | 10 | 0 |

### 4.2.10 Method used to minimize machines failure

The Table 4.9 Expressed that method used to minimize machines failure based the questions was stated below. The first question was, there was overall equipment evaluation calculated to monitor the condition of critical equipment; on this point the respondents responded as follow; 5% strongly agreed, 15% agreed, 15% neutral, 38.33% disagreed, and 26.67% strongly disagreed. From the data figure, the most of the respondents responded there was no overall equipment evaluation calculated to monitor the condition of critical equipment.

The second question was, the company had failure analysis conducted by the use of an analysis tool such as fishbone, Statistical Process Control (SPC) and others to assure accuracy and standardization for each analysis; on this point the respondents responded as follow; 1.67% strongly agreed, 8.33% agreed, 16.67% neutral, 21.66% disagreed, and 51.67% strongly disagreed. From the data figure, the most of the respondents responded the company had no failure analysis conducted by the use of an analysis tool such as fishbone, Statistical Process Control (SPC) and others to assure accuracy and standardization for each analysis. For this reason, the organization should be used this methods to analyzed the failurity of machinery.

The third question was, there was a method which increased reliability of machines; on this point the respondents were responded as follow; 5% strongly agreed, 21.67% agreed, 10% neutral,

36.67% disagreed, and 26.67% strongly disagreed. From the data, the most of the respondents responded there was no a method which increased reliability of machines. The fourth question was, the organization believe that improving maintenance could increase the reliability of production system; on this point the respondents responded as follow; 26.67% strongly agreed, 50% agreed, 8.33% neutral, 5% disagreed, and 0% strongly disagreed. From the data, the most of the respondents responded the company believed that improving maintenance could increase the reliability of production system.

**Table 4.9:** Frequency for Method used to minimize machines failure

| **Method used to minimize machines failure** | | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|---|
| There is overall equipment evaluation calculated to monitor the condition of critical equipment. | Freq. | 3 | 9 | 9 | 23 | 16 |
| | % | 5 | 15 | 15 | 38.33 | 26.67 |
| The company had failure analysis conducted by the use of an analysis tool such as fishbone, Statistical Process Control (SPC) and others to assure accuracy and standardization for each analysis. | Freq. | 1 | 5 | 10 | 13 | 31 |
| | % | 1.67 | 8.33 | 16.6 | 21.66 | 51.67 |
| You have a method which increases reliability of machines. | Freq. | 3 | 13 | 6 | 22 | 16 |
| | % | 5 | 21.67 | 10 | 36.67 | 26.67 |
| The organization believes that improving maintenance could increase the reliability of production system. | Freq. | 22 | 30 | 5 | 3 | 0 |
| | % | 26.67 | 50 | 8.33 | 5 | 0 |
| The machines perform their required function for the specified time. | Freq. | 3 | 14 | 5 | 30 | 8 |
| | % | 5 | 23.33 | 8.33 | 50 | 13.33 |

The fifth question was, the machines perform their required function for the specified time; on this point the respondents responded as follow; 5% strongly agreed, 23.33% agreed, 8.33% neutral, 50% disagreed, and 13.33% strongly disagreed. From the data, the majority of the respondents responded the machines were not performed their required function for the specified time.

### 4.3 Documentation Review

Metahara Sugar Factory Maintenance Department sections are:

**1. Mechanical Maintenance team activities**

- Performed daily routine like, cleaning, belt tightening, machinery's foundation tightening, lubrication, inspection, maintained machineries in general.
- Order the spare parts like shafts, gears, couplings, pins, sprockets, pulley, knives, rollers were ordered to be manufactured or reconditioned.
- Prepare machineries specifications and technical evaluation for internal and external purchasing.
- Prepare activity plan during maintenance.

2**. Electrical Maintenance**

- Their main activities were inspection, repair, motor rewinding, maintained electrical components and any other electrical units.
- Installation and maintenance of power supply unit and lines.

**3. Instrumentation Maintenance**

- Maintenance of all instruments like actuators, transmitter, valves and control mechanism of the units.

**4. Workshop**

The duties of the workshop are:

- Fabricate spare parts of machine components like pin, gear any other components according to order of plants.
- Preparing spare parts as stand by giving priority.
- To recondition of machine components like shaft's bearing seat, coupling seat, gear seat, oil seal seat, etc. based on customer order.
- To prepare bill of material.
- To repair workshop machinery.
- Preparing elbow for high vacuum lines.

### 4.2 Work Flow of existing maintenance

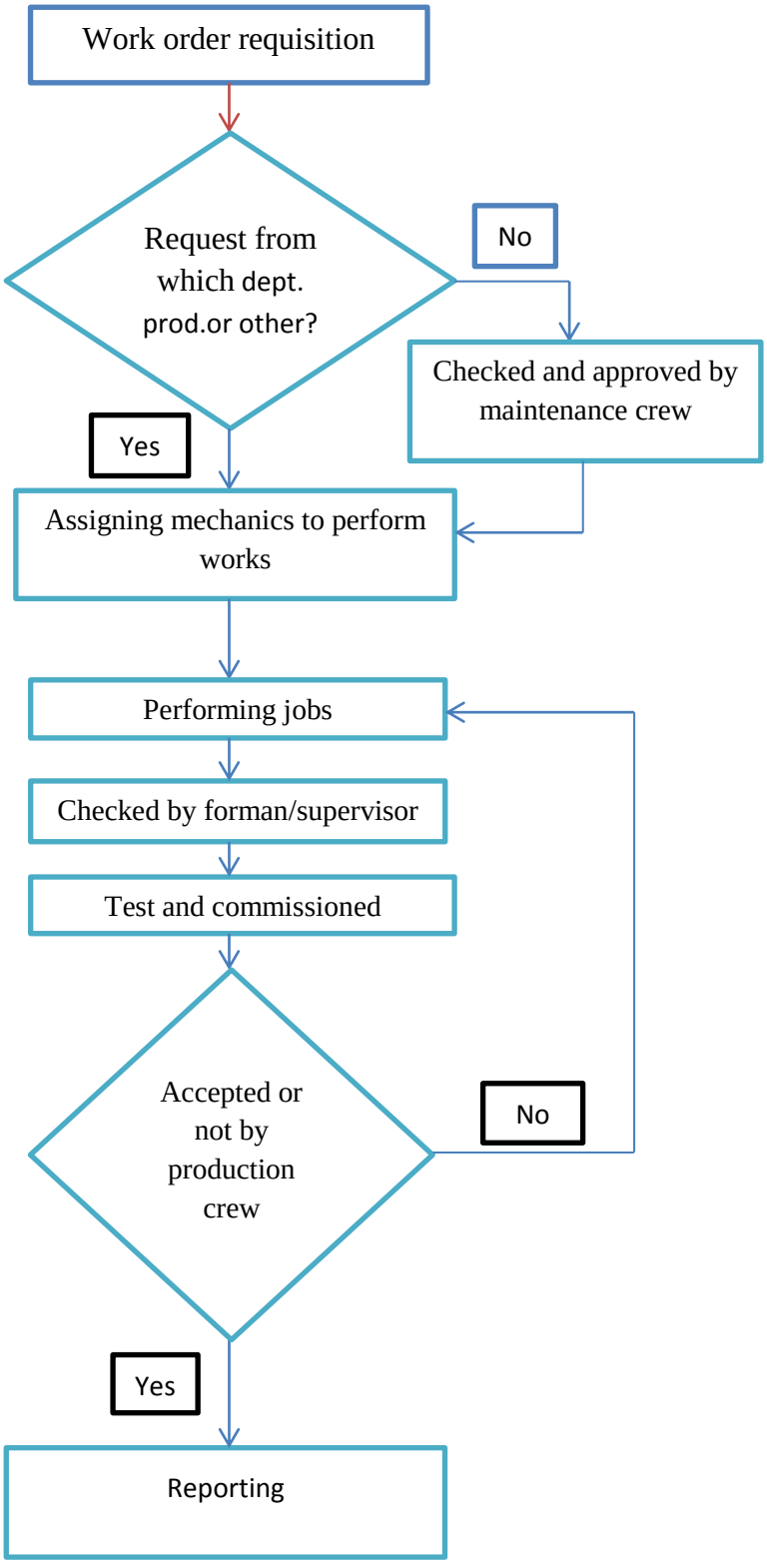



Figure 4.3 Existing maintenance work flow for breakdown

Figure 4.3 described in Metahara Sugar Factory the maintenance tasks were performed in two ways; when machines were failed that was corrective maintenance was done and when the works were generated from the maintenance plan. When breakdown occurs the production department informs the maintenance department by requisition paper. After receiving the request, the maintenance team of forman supervisor, senior, and team leader identify the cause of failure and pass the works order to mechanics or operators to perform the jobs. Finally, the performed jobs checked and approved by forman, supervisor and senior and reported to team leaders. There were also maintenance works scheduled as planned maintenance to replace parts and overhaul of machineries.

### 4.3.1 Evaluation of performance

Evaluation of plan and actual performance was investigated for five years. Table 4.10 and Figure 4.4 showed that the plan and actual cane crushed of the production year from 2017/18-2021/22.The cane crushed increased from 2017/18 to 2020/21 and decreased from 2020/21 to 2021/22 in volume. The campaign year 2021/22 the least crushing year due to the crushing time duration was the least relative to the other campaign and more down times. In general the cane crushing decreased due to mainly high machineries down times in the factory.

Performance was calculated by the ratio of actual cane crushed to plan of cane crushed.

$$\text{Performance} = \frac{\text{Actual cane crushed in tons}}{\text{Plan of cane crushed tons}} \quad (4.1)$$

**Table 4.10:** Plan of cane crushed and Actual of cane crushed

| S/N | Production year | Plan of cane crush in tons | Actual of Cane crushed in tons |
|---|---|---|---|
| 1 | 2017/18 | 919,517.80 | 741,048.40 |
| 2 | 2018/19 | 956,394.00 | 751,649.00 |
| 3 | 2019/20 | 988,817.00 | 897,191.20 |
| 4 | 2020/21 | 1,008,743.30 | 889,510.60 |
| 5 | 2021/22 | 1,008,743 | 526,781.70 |

Figure 4.4 described that the plan and actual of sugar produced of the production year from 2017/18-2021/22.The sugar produced slightly decreased from 2017/18 to 2018/19 and increased

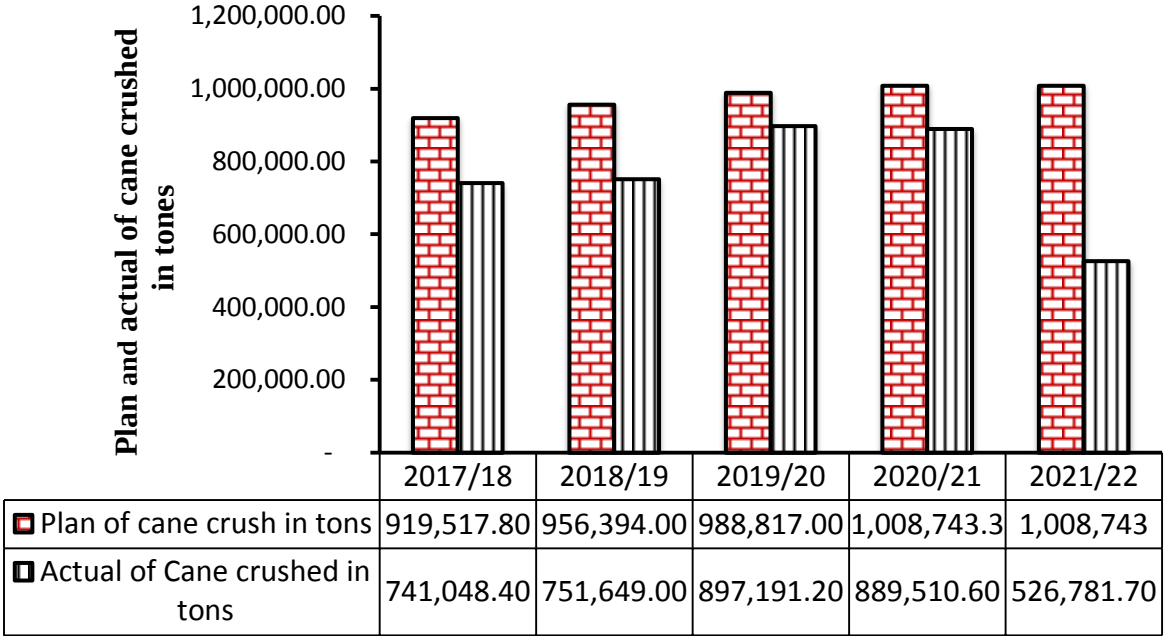
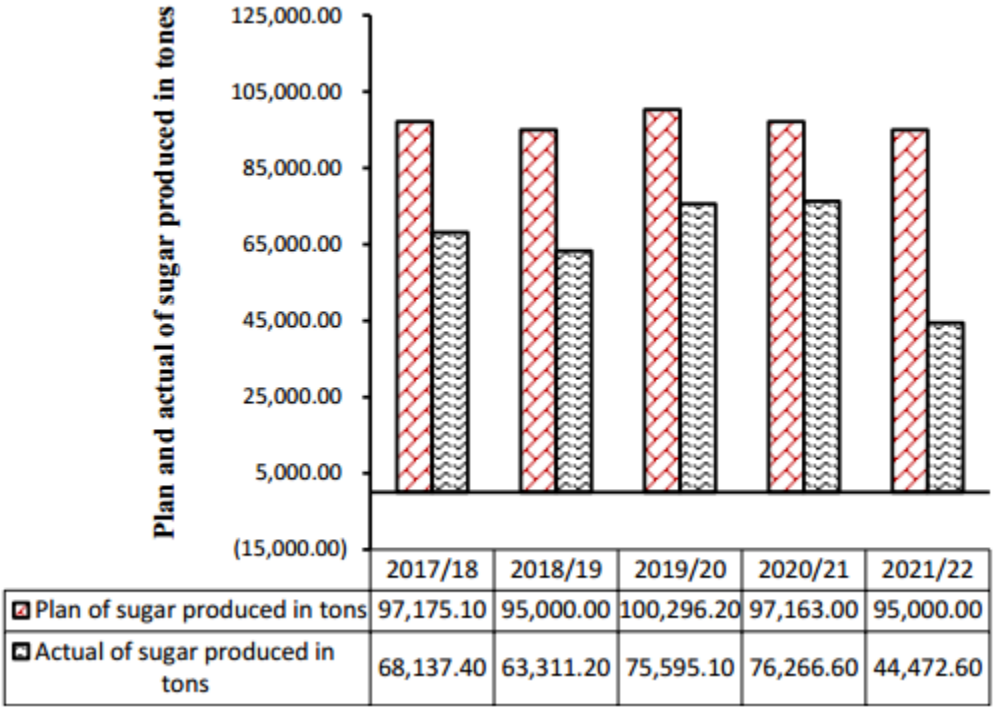



**Figure 4.4**: Plan of cane crushed and Actual of cane crushed

**Table 4.11:** Plan and Actual of sugar produced in tons

| Production year | Plan of sugar produced in tons | Actual of sugar produced in tons |
|---|---|---|
| 2017/18 | 97,175.10 | 68,137.40 |
| 2018/19 | 95,000.00 | 63,311.20 |
| 2019/20 | 100,296.20 | 75,595.10 |
| 2020/21 | 97,163.00 | 76,266.60 |
| 2021/22 | 95,000.00 | 44,472.60 |

from 2018/19 to 2020/21 in volume. The campaign 2021/22 the least sugar produced year due to the crushing time duration was the least relative to the other campaign and down times. In general the sugar produced decreased due to mainly high machineries down times and other factors.




| | 2017/18 | 2018/19 | 2019/20 | 2020/21 | 2021/22 |
|---|---|---|---|---|---|
| Plan of sugar produced in tons | 97,175.10 | 95,000.00 | 100,296.20 | 97,163.00 | 95,000.00 |
| Actual of sugar produced in tons | 68,137.40 | 63,311.20 | 75,595.10 | 76,266.60 | 44,472.60 |

**Figure 4.5:** Plan and Actual of sugar produced in tons

### 4.3.2 Productivity Analysis

Productivity is an average measure of the efficiency of production. It can be expressed as the ratio of output to inputs used in the production process, i.e. output per unit of input. When all outputs and inputs are included in the productivity measure it is called total productivity. Outputs and inputs are defined in the total productivity measure as their economic values. The value of outputs minus the value of inputs is a measure of the income generated in a production process. It is a measure of total efficiency of a production process and as such the objective to be maximized in production process (Marwah, 2015). Productivity defined as the ratio between the output volume (sugar bagged) and the volume of inputs(cane crushed).

$$\textbf{Productivity} = \frac{\text{Actual sugar produced}}{\text{Plan cane crushed}} \qquad (4.2)$$

The Productivity of the factory was maximum (0.89) for the years of production 2020/21 and 2021/22. This confirms that resources were well utilized. However, Sugar produced in these years were less than the others years. This analysis showed that for the last three years from 2017/18 to 2019/20 productivity linearly decreased. This needs an investigation.

**Table 4.12:** Percentage of cane crushed and sugar produced

| S/N | Production year | % cane crushed | % Sugar produced |
|---|---|---|---|
| 1 | 2017/18 | 80.59 | 70.12 |
| 2 | 2018/19 | 78.59 | 66.64 |
| 3 | 2019/20 | 90.73 | 75.37 |
| 4 | 2020/21 | 88.18 | 78.49 |
| 5 | 2021/22 | 52.22 | 46.81 |

**Table 4.13:** Productivity efficiency

| S/n | Production year | Productivity |
|---|---|---|
| 1 | 2017/18 | 0.87 |
| 2 | 2018/19 | 0.848 |
| 3 | 2019/20 | 0.83 |
| 4 | 2020/21 | 0.89 |
| 5 | 2021/22 | 0.89 |

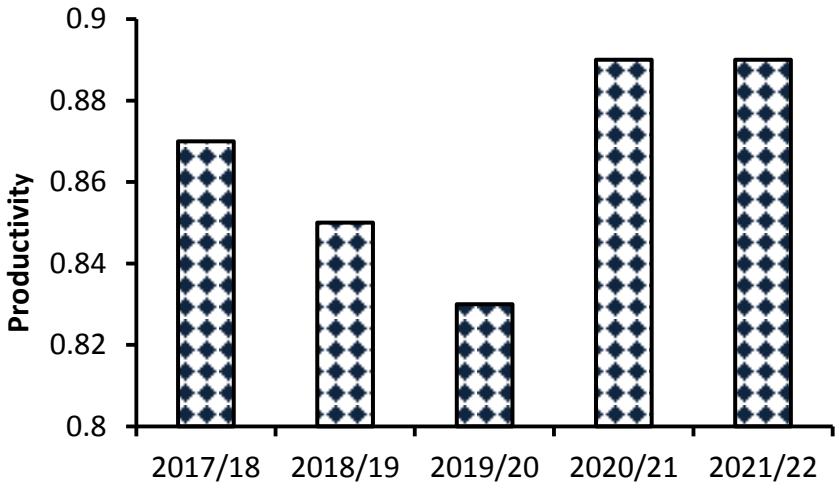



**Figure 4.6** Productivity efficiency analyses

### 4.4 Analysis of factory down time

In the Metahara Sugar factory under mechanical maintenance section there are two tandems (Tandom A (TA) and Tandom B (TB), boiler and process house sections (clarification, Evaporation, Vacuum and centrifugal) plants. TA contains cane handling A (CHA) and Milling A (MA), TB contains cane handling B (CHB) plant and Milling B (MB) plant. Table 4.14 and Figure 4.6 explained and supported to know the current condition of the company using data documented on 2017/18 to 2021/22 campaign years of machineries down times. Quantitative data from quality, technical and planning departments, about machine down time status as per recorded data described on Figure 4.7. The Figure 4.7 showed that the down time increased from 2017/18 to 2019/20 and decreased from 2019/20 to 2021/22 campaign years.

**Table 4.14**: Machineries down time of 2017/18 to 2021/22 years

| | Machineries down times | |
|---|---|---|
| **S/n** | **Year** | **Down times(hours)** |
| 1 | 2017/18 | 3011.15 |
| 2 | 2018/19 | 3474.67 |
| 3 | 2019/20 | 3721.83 |
| 4 | 2020/21 | 2889.15 |
| 5 | 2021/22 | 1530.15 |

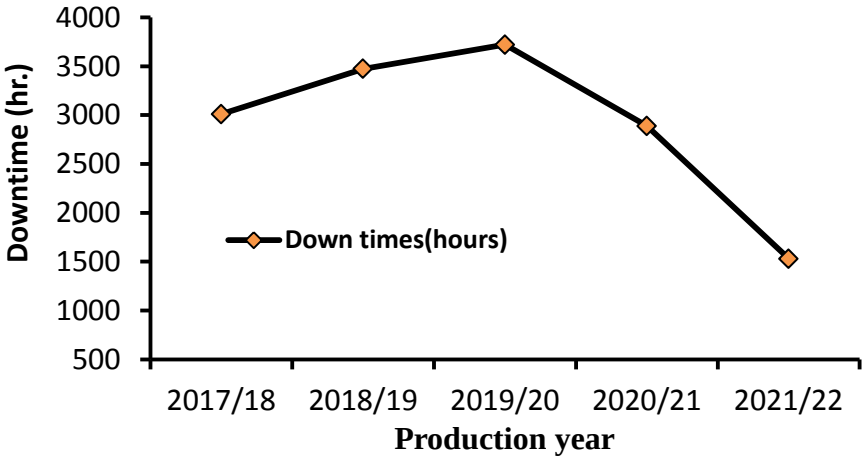



Figure 4.7 Machineries down time

As described in the Figure 4.7 the machineries down time was the highest in 2019/20 operation campaign which needed further investigation. To change the curve of Figure 4.7 the company should be implemented the preventive and predictive maintenance strategy to minimize machineries down times and increase productivity. During 2020/21 production campaign, the productivity was the best due the spare parts of the machineries were bought relative to other years. In 2021/22 production campaign year the factory operated for five months due to environmental factors and after machineries overhaul maintenance was done the machineries operated effectively because machineries spare parts were new, reconditioned and the deteriorating of machines components not visible for the first half or five months operation due to these reasons the factory productivity is best and the minimum down times recorded.

### 4.4.1 Analysis of each down times of machineries

**Mechanical down time:**

The causes of mechanical down time were occurred due the failure of machines components, like failure of bearings, worn out of gears, bending of rotating shafts, worn out of sprockets, vibration, poor alignment, poor adjustment, poor quality of spare parts, machineries were aged, poor preventive maintenance(cleaning, belt tightening, bolt tightening, belt dressing, temperature checking), unavailability of spare parts, fluctuating loads on unit of machines, poor lubrication, wearage, friction, over speed, maintenance-related factors, poor maintenance strategy, design-related factors and employee-related factors.

**Table 4.15:** Mechanical down times

| | 2017/18-2021/22 Mechanical down time(hours) | |
|---|---|---|
| S/n | Year | Mechanical down time(hours) |
| 1 | 2017/18 | 1844.7 |
| 2 | 2018/19 | 1898.05 |
| 3 | 2019/20 | 2141.81 |
| 4 | 2020/21 | 2001.25 |
| 5 | 2021/22 | 1152.6 |

Table 4.15 and Figure 4.8 illustrated that the mechanical down time increased from 2017/18 to 2019/20 campaign years and declined from 2019/20 to 2021/22. The down was highest in 2019/20 due to the high break down of machineries or components failed mechanically due to

mainly maintenance problem in the factory. The smallest mechanical down times recorded in 2021/22 campaign year because of other factors like, environmental and the factory operate only for five months and this make the smallest from other campaign years.

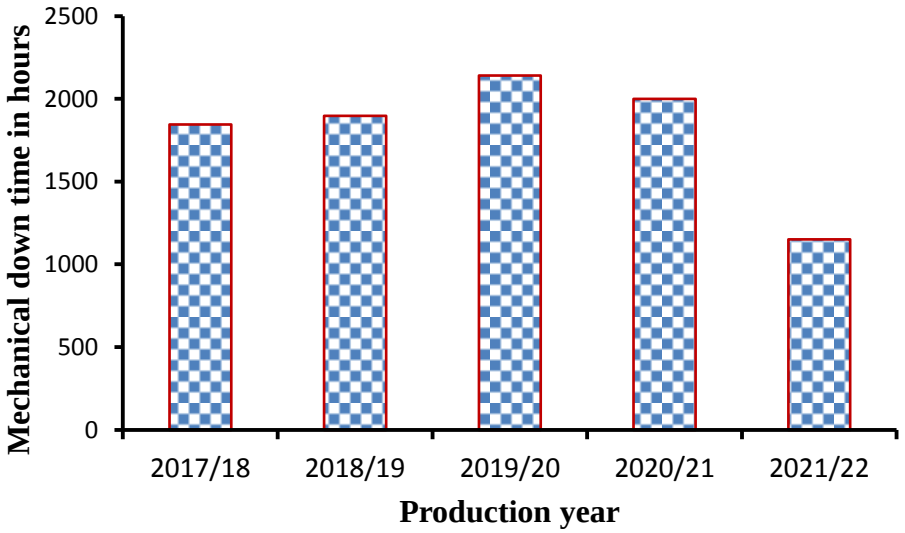



**Figure 4.8** Analysis of mechanical down times

**Electrical down times:**

Table 4.16 and Figure 4.9 illustrated that the electrical down time increased from 2017/18 to 2019/20 production campaign, then decreased from 2019/20 to 2021/2022 production campaign. The electrical down times appeared in the factory due to electrical equipment, like when motor burnt, misalignment, fluctuating load and when mechanical component failed were the cause of electrical problem. The electrical problem had very less when compared to mechanical problem. So, to avoid this down times machineries preventive maintenance was recommended.

**Table 4.16** Electrical down times

| 2017/18-2021/22 Electrical down time (hours) | | |
|---|---|---|
| S/n | Year | Electrical down time(hours) |
| 1 | 2017/18 | 139 |
| 2 | 2018/19 | 105.5 |
| 3 | 2019/20 | 256.75 |
| 4 | 2020/21 | 101.95 |
| 5 | 2021/22 | 37 |

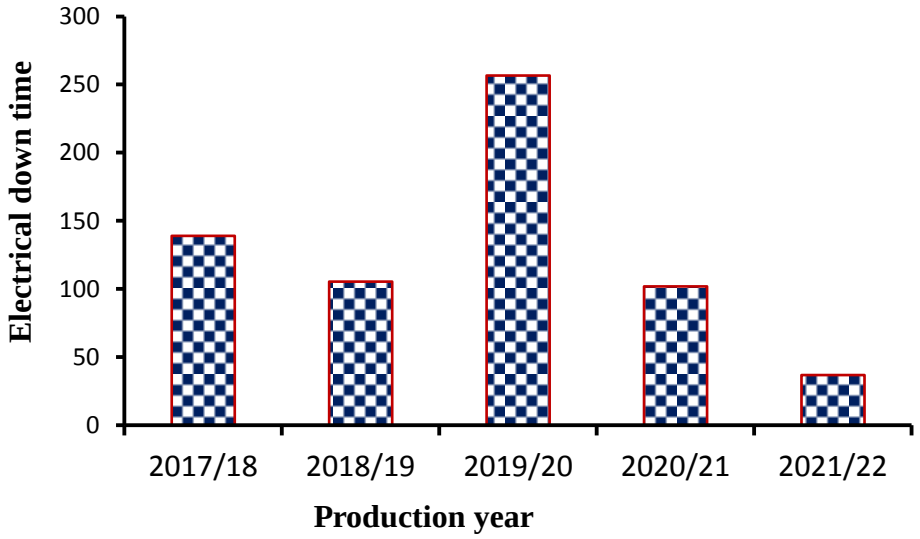



Figure 4.9 Analysis of electrical down times

**Instrument down time:**

The Table 4.17 and Figure 4.10 showed that the instrument down times increased from 2017/18 to 2018/19, then decreased in from 2019/20 to 2020/21. Then, the finally increased in 2021/22 campaign years. This down time had less impact relative other down times. More attention should be given to the equipments to minimize this down time.

**Table 4.17** Instrument down time

| | **2017/18-2021/22 Instrument down time (hours)** | |
|---|---|---|
| **S/n** | **Year** | **Instrument down time(hours)** |
| 1 | 2017/18 | 13.75 |
| 2 | 2018/19 | 30.25 |
| 3 | 2019/20 | 3.5 |
| 4 | 2020/21 | 13 |
| 5 | 2021/22 | 6.75 |

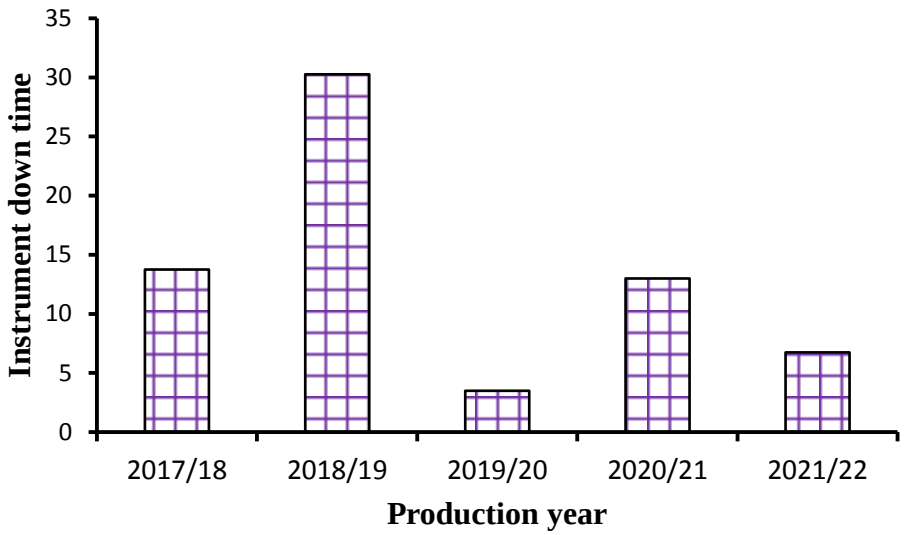



Figure 4.10 Analysis of instrument down time

**Blockage down time:**

Table 4.18 and Figure 4.11 showed that the blockage down times increased from 2017/18 to 2019/20, and then become reduced in from 2019/20 campaign years. Then, decreased from 2019/20 to 2021/22 years. This fluctuation occurred due to machineries malfunctioning and operation problems. This down time occurred due operators and mechanical problem occurred on the machinery this brought the blockage on the units. So, training the operators and minimizing mechanical failure the down time could minimize.

**Table 4.18** Blockage down time

| S/n | 2017/18-2021/22 Year | Blockage down time (hours) |
|---|---|---|
| 1 | 2017/18 | 111.7 |
| 2 | 2018/19 | 309.6 |
| 3 | 2019/20 | 571.26 |
| 4 | 2020/21 | 394.29 |
| 5 | 2021/22 | 72.25 |

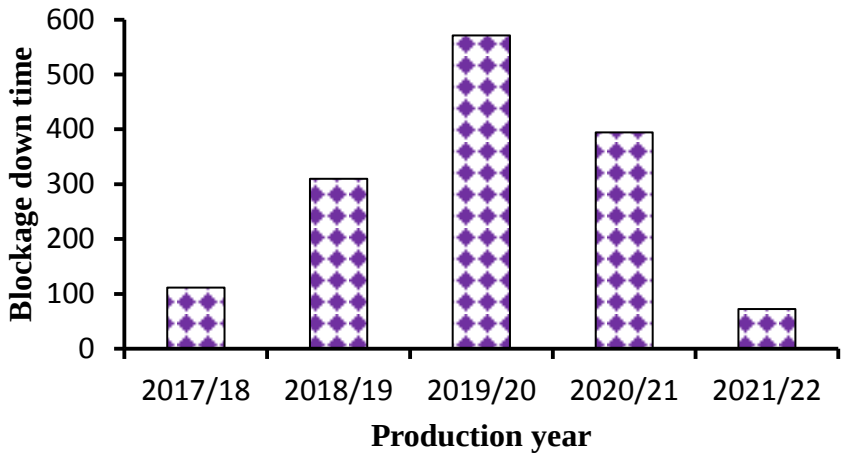



**Figure 4.11** Blockage down time Analysis

**Others down times:**

The Figure 4.12 and Table 4.19 showed that the other down time decreased from 2017/18 to 2019/20 production campaign and increased in 2020/21, then decreased in 2021/22 operation campaign. This down time occurred, for example when the cane transported to the factory from the stone came with cane and broken the equipments. This type of down time called as other down time in the factory.

**Table 4.19** Others down time

| | 2017/18-2021/22 Others down time(hours) | |
|---|---|---|
| S/n | Year | |
| 1 | 2017/18 | 90 |
| 2 | 2018/19 | 32 |
| 3 | 2019/20 | 6.25 |
| 4 | 2020/21 | 24.25 |
| 5 | 2021/22 | 19.5 |

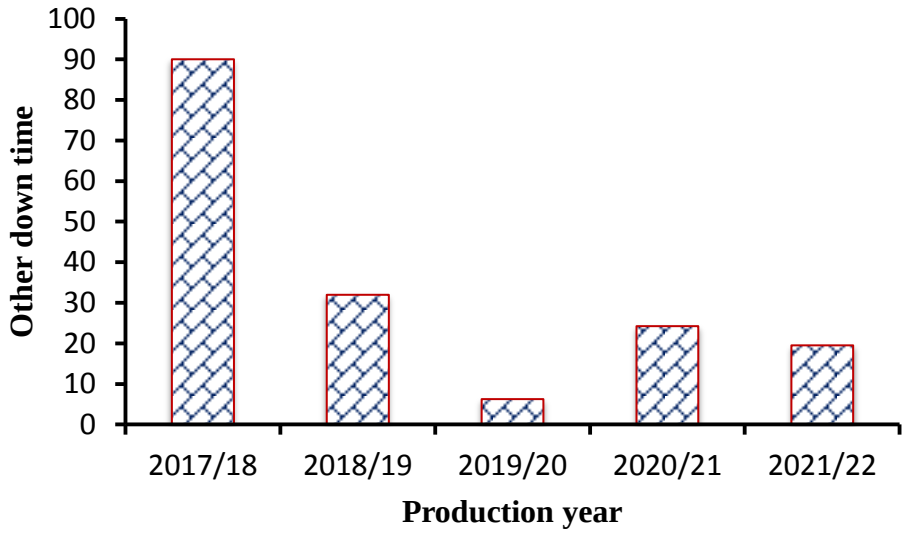



Figure 4.12 Others down times analysis

**Preventive maintenance down time:**

Table 4.20 and Figure 4.13 showed that preventive maintenance down time increased from 2017/18 to 2018/19 production campaign year and linearly decreased from 2018/19 to 2021/22 production campaign. Even though, the organization not implemented the preventive maintenance correctly if on other plant high time taken failurity occur, by taking other plant down time as opportunity the other plant done preventive maintenance without any plan. The preventive maintenance could be minimized by performing the activities like, before operation the machineries and machineries components should be maintained by standard, quality, durable spare parts which worked for long period of time without failurity.

**Table 4.20** Preventive maintenance down time

| | 2017/18-2021/22 Preventive maintenance down time(hours) | |
|---|---|---|
| **S/n** | **Year** | **Preventive maintenance down times(hours)** |
| 1 | 2017/18 | 99.25 |
| 2 | 2018/19 | 102.25 |
| 3 | 2019/20 | 64 |
| 4 | 2020/21 | 60.25 |
| 5 | 2021/22 | 31.45 |

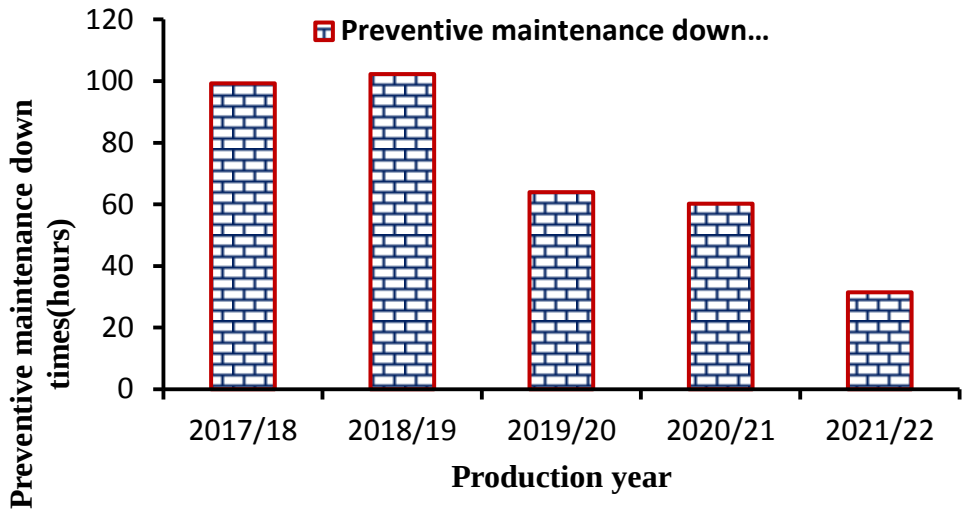



Figure 4.13 Analysis of preventive maintenance down times

**Pressure drop down time:**

Figure 4.14 and Table 4.21 showed that the steam pressure drop down time increased from 2017/18 to 2018/19 operation campaign and decreased from 2019/20 to 20221/22 campaign years. This down time was highly affecting the productivity because if boiler not generated steam the factory was out function. So, to minimize this down time the boiler plant should applied the preventive maintenance strategy which provide fruitful result on productivity.

**Table 4.21** Pressure drop down time

| | **2017/18-2021/22 Pressure drop down time(hours)** | |
|---|---|---|
| **S/n** | **Year** | **Pressure drop down time(hours)** |
| 1 | 2017/18 | 656.5 |
| 2 | 2018/19 | 906.52 |
| 3 | 2019/20 | 489 |
| 4 | 2020/21 | 179.26 |
| 5 | 2021/22 | 140 |

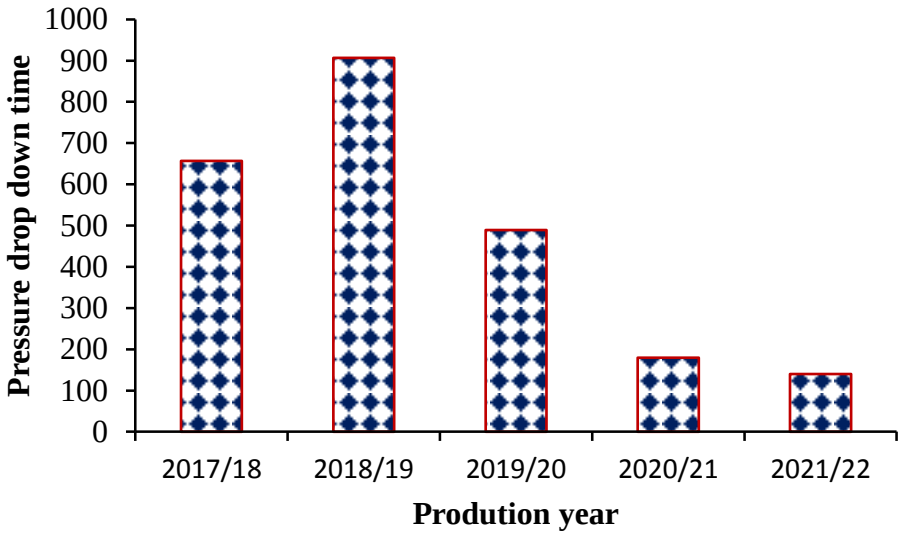



**Figure 4.14** Pressure drop down time analysis

**Lack of steam down times:**

Table 4.22 and Figure 4.15 showed that down times due to lack of steam reduced from 2017/18 to 2018/19, then raised in 2019/20, then reduced from 2019/20 to 2021/22 operation campaigns. This down time based on the efficiency of the boiler. If boiler performed efficiently this down time can be avoided or minimized. Organized maintenance should be applied on this plant to maximize productivity.

**Table 4.22** Lack of steam down time

| **2017/18-2021/22 Lack of steam down time(hours)** | | |
|---|---|---|
| **S/n** | **Year** | **Lack of steam down time(hours)** |
| 1 | 2017/18 | 156.25 |
| 2 | 2018/19 | 92.5 |
| 3 | 2019/20 | 149.26 |
| 4 | 2020/21 | 114.75 |
| 5 | 2021/22 | 70.45 |

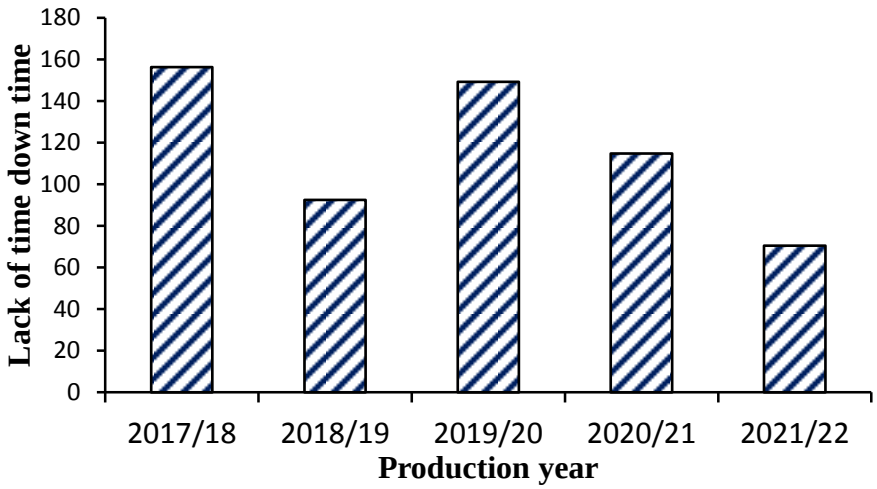



**Figure 4.15** Lack of steam down time analysis

### 4.5 Productivity declines due to machineries/ machineries component failure

The compared between the percentage of the sugar produced and the amount of cane crushed stated in the graph on Figure 4.1. Based on this, the graph indicated that there were high machineries down times, with the high production volume and lowest productivity observed during the operational campaign of 2019/20. In this production campaign the mechanical down time high in extraction section like milling a(ma), milling b(mb) and the cane handling plant; like cane handling a (cha) and the cane handling b(chb) and in the boiler plant pressure drop and lack of steam.

**Cane handling:**

Cane handling the plant used to transport the cane from cane yard to extraction/ milling section. Cane handling includes the following parts.

These are:

a. Cane unloaders (hillo crane)
b. Cane tables
c. Auxilliary cane carrier
d. Cane cutter/knives(roughing, first finishing and febrizer)
e. Elevator cane carrier
f. Band cane carrier

On the above described parts, mechanical failures highly occurred due to reasons like, vibration, alignment, bearing failure, deformed of cane carrier slats, worn out drive and driven sprocket,

worn out of bushing component, deformed of( strips, angle iron, square bar, small board, etc), wearage of component, fatigue, different load on units, mechanics/operators error, etc

**Extraction section:**

Extraction is a section used to extract juice from the cane and sent the juice to process house by using pumps and sent the bagasse for the boiler plant used which used as a fuel to generate steam. These sections include the following parts.

These were:

a. Mills
b. Mill turbines
c. Intermediate bagasse carrier (IMBC)
d. Outlet bagasse carrier

**Mills:**

The milling process extracting juice from the cane by using three set rollers according to their dimensions. The millings were arranged in series, called mill#1, mill #2, mill#3, mill#4 and mill#5. Between those mill there were intermediate bagasse carrier which used to transported bagasse from one mill to another mill to extract juice from the efficiently. In this section the mechanical failure occurred due to; mill setting problem, worn out of rollers journal bearings, poor alignment, roller scrapper mounting, worn out shafts bushings, hydraulic, unavailability of spare parts, lubrication problem, poor preventive maintenance (inspection, checking temperature of units, roller pinion worn out due to fluctuating loads and quality of materials, operators/mechanics.

**Mill turbines:**

Mill turbine used to drive the mill rollers at the required mill roller speeds. The turbine was driven by steam which generated from power generation plants. Its components failed mainly due to mechanical of failure. While in operation, the mill turbine failed due to poor inspection, improper preventive maintenance, unavailability of spare parts, lubrication, improper its component adjustment, operators/mechanics, fatigue, wear friction, etc. So, the units provided high down times.

**Intermediate bagasse carrier:**

Intermediate bagasse carrier **(**IMBC**)** used to convey the bagasse from one mill discharged to another mill. Mechanical failure occurred on the unit due to poor inspection, lubrication, poor preventive maintenance.

**Out let belt:**

The outlet belt used to conveying or transporting the final dry bagasse to boiler plant which used as fuel to generate the steam. This unit stopped due to failure drive sprocket, worned of idlers, adjustment problem and other factors.

### 4.6 Conceptual Framework

#### 4.6.1 Set maintenance strategy

This should be determined according to the company vision ,mission and goal and differentiating maintenance strategy is very important to understand the main role of maintenance crew in the company.

The objective includes:

- To handle safely machineries by close follow up of its status.
- To increase machineries availability by inspection to detect their failurity immediately.
- Improve the skills and knowledge of the maintenance crew.
- Ensure the availability of spare parts, materials according to maintenance standard and quality.

#### 4.6.2 Differentiate current problem section

Overall equipment effectiveness (OEE) was a key indicators tool for understanding, managing and controlling the manufacturing operation. In its basic form, it is expected to distinguished production obstacles, firstly. So, could be managed, for example, machineries breakdown, other wastes, and quality, and this look simple in idea, but much challenged in practice. Identify critical machineries or equipments of the bottle neck: Failure mode and effect analysis performed to identify critical plants or machineries/components based on the failure rate.

#### 4.6.3 Select maintenance strategy

Tacit and explicit knowledge used due to incomplete data (Lundgren et al., 2018). Based on the discussion with technical staff' preventive and predictive maintenance is selected for machineries maintenance. Besides to this, autonomous maintenance is best for the company because there were skilled employers in the organization and autonomous maintenance selected

to perform planned maintenance. Because autonomous maintenance empowers operators or mechanics to reduce breakdown times and perform good maintenance.

### 4.7 Maintenance performance evaluation indicator

The managers required to know about the performance to monitor, evaluate and control the maintenance activities process and output given ways towards enhancing productivity. Performance measures of maintenance used to obtain machineries performance. The managers easily know the efficiency and effectiveness of maintenance tasks if there were maintenance performance indicators, join inputs and outputs, and therefore reasonable budget in maintenance. The maintenance measurement indicators such as, OEE, RCA had been widely accepted as vital for the management of maintenance operations. Therefore Metahara Sugar Factory will have the information and known about the performance of equipments when used the maintenance measurement indicators.

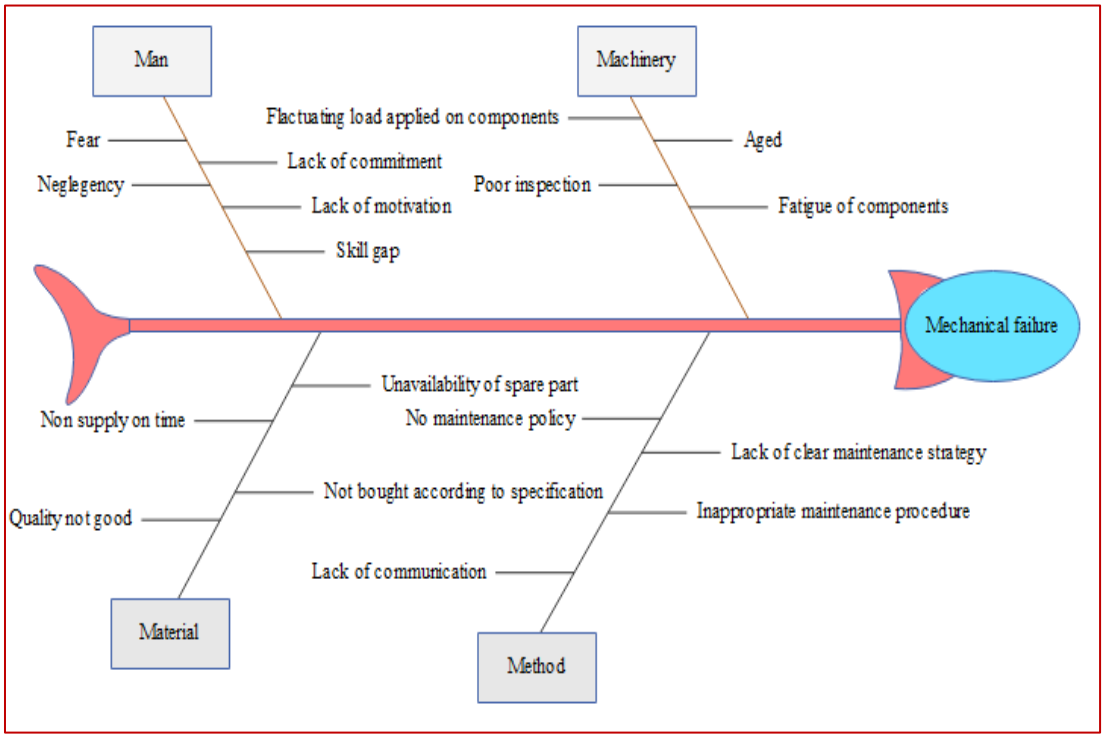



Figure 4.16 Cause and effect of the failurity of machinery

Figure 4.16 A cause and effect diagram described that the causes of any mechanical failure of the machines. It also named as Ishikawa diagram or fishbone diagram (due to their arrangement). An

Ishikawa or cause and effect diagram was structured to differentiate the causes of mechanical failures that highly affect productivity.

### 4.8 Six Sigma Approach

Six Sigma is a system used to solve the problem by applying the DMAIC which is Define, measure, Analyze and control. By implementing these principles the failure of machinery was analyzed to minimize downtimes. The application of the Six Sigma problem solving methodology, DMAIC, reduced the down times and other productivity obstacles. The use

DMAIC process to solve problems. The DMAIC is problem solving steps which contains five phases in which needed to take measures on the problems. The DMAIC process includes a DMAIC pattern which includes the following steps:

**Step one is the define phase:**

The objective of the organization was to enhance productivity through mainly minimization down time. Downtimes were the major cause of decline of productivity and production. The performance of the machineries directly impacts on the overall efficiency of the organization. To understand the process and its challenges, using suppliers, input, process, and customer(SIOPC).

**Step two is the measure phase:**

Collection of data from maintenance machine break down, measure the collected data, by using cause and effect diagram and identify the root causes of the failures.

**Step three is the analysis phase:**

This phase is to identify the root-cause that was causing the problem. For this step, problem needed to visualize and the data collected, use a fishbone diagram to capture the knowledge of the process participants during the session, and use the 5 whys diagram to narrow down the findings to the last few causes of the problem.

**Step four is the improvement phase:**

Solve the problem in the machineries breakdowns through root cause analysis for major problem in each section related with cause of machineries failure. The following Table 4.23 shows the root cause and their remedy of the machineries component failure with respect plants.

**Step five is the control phase:**

In this phase, better to continue the improvements obtained already implemented in the improvement phase. Build a monitoring plan for the improvements and a response plan in case there are machineries downtimes.

**Table 4.23**: Failure mode and effect analysis of machineries

| S.N | Plant name | Machine /component failed | Frequency of failure per week | Causes failure | Preventive activity | Remedy |
|---|---|---|---|---|---|---|
| 1 | Cane handling a(cha) | Cane unloaders | 3 | -Pulley worn out<br>-Bushings worn out<br>-wire cable detached<br>-pins sheared<br>-bearing failed<br>-hosting drum worn out | -Inspection<br>-Re-grease<br>-Refreshing bearings<br>-lubrication | -Repair<br>-Change |
| | | Cane table | 3 | -transport chain detached<br>-chain link pin worn out<br>-strip wear<br>-drive sprocket teeth worn out | Inspection<br>-Re-grease<br>-Refreshing bearings<br>-lubrication | -Replace<br>-Welding |
| | | Horizontal cane carrier | 5 | -chain link detached<br>-pin worn out<br>-drive sprocket bearing failed<br>-bushing worn out | Inspection<br>-Re-grease<br>-Refreshing bearings<br>-lubrication | -Replace<br>-Welding |
| | | Anvil cane carrier | 2 | -chain link detached<br>-pin worn out<br>-drive sprocket bearing failed<br>-bushing worn out | Inspection<br>-Re-grease<br>-Refreshing bearings<br>-lubrication | -Replace<br>-Welding |
| | | Rake cane carrier | 7 | -drive sprocket teeth are worned out<br>-chain roller worned out<br>-chain links are detached<br>- link pins are sheared<br>-forks are bended/broken | Inspection<br>-Re-grease<br>-Refreshing bearings<br>-lubrication | -Replace<br>-Welding |
| | | Inclined cane carrier | 2 | -slats are bended/broken<br>-slats tightening bolts are broken<br>-drive sprocket teeth are worned out<br>-bearings are failed | Inspection<br>-Re-grease<br>-Refreshing bearings<br>-lubrication | -Replace<br>-Welding |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | Cane cutters | 4 | -knives are broken<br>-drive bearings are failed<br>-vibration<br>-structure cracked | -checking vibration<br>- check structure cracking | -Replace<br>-Welding |
| | | | 7 | -knives are broken<br>-drive bearings are failed<br>-vibration<br>-structure cracked<br>-knives domite tip are worned out | checking vibration<br>- check structure cracking | -Replace<br>-Welding |
| 2 | Milling a(ma) | Mills and accessories Mill turbines and accessories | 9 | -tail bar couplings are sheared.<br>-top roller scrapper adjustment bolts and its frame broken.<br>-rollers drive pinions are worned out<br>-under feed roller drive chain is detached.<br>- under feed roller drive sprocket teeth worned out.<br>-rollers teeth groove are worned out.<br>-delivery roller scrapper adjust bolts are broken. | -close inspection | -Replace<br>-Welding |
| | | | 5 | -shaft's thrust bearing seats are worned out.<br>- shaft's radial bearing seats are worned out.<br>-driving gears worned out.<br>-axial of the units<br>-lybriths (steam guard) worned out.<br>-oil guard worned out<br>- turbine blade worned out.<br>-speed reduction tachometer pinions are worned out.<br>-oil cooler pipes are worned out.<br>-admission valve adjustment problem<br>-governor adjustment problem.<br>-operating and lubrication oil pressure are under. | -inspection | -Changed |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | Transmission Gear boxes and accessories | 3 | -speed reduction gear worned out.<br>-bearing are failed<br>-oil cooler tubes are worned. | -Inspection | -Replace |
| | | Intermediate Bagasse carrier | 4 | -slats are broken and bended<br>-strips are worned out<br>-bearings are failed<br>-drive sprocket worned out<br>-bush bearings are worn out.<br>-drive chain link detached.<br>-drive chain pins are worned out/broken. | -Inspection | -Replace<br>-Repair |
| | | Pipelines, Valves & tanks | 4 | -pipes worned out.<br>-valves are damaged<br>-tanks are worned out | -Inspection | -Repair<br>-Change |
| 3 | Milling b(mb) | Mills and accessories | 8 | - tail bar couplings were sheared<br>-mill suspension bolts broken<br>- mills setting problem<br>-hydraulic oil hose connection union teeth damaged.<br>-scrappers adjustment bolts are broken.<br>-trash plate adjustment bolts are loosen.<br>-donnelly chute adjustment<br>- hydraulic cap bearings are failed.<br>-scrapper plate bolts are sheared.<br>- trash plate grooves are worned out<br>-rollers grooves are worned out<br>-roller drive pinion teeth worned out | -Inspection | -Repair<br>-Change |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | Intermediate bagasse carrier | 4 | -forks were bended and broken.<br>-drive chain was detached.<br>-drive pins were sheared.<br>-drive sprocket teeth were worned out.<br>-bearings were failed.<br>-bushings were worned out<br>-side strips were detached. | -Inspection | -Repair<br>-Change<br><br>-Repair<br>-change |
| | | Cush-cush screening and conveying system | 4 | - shaft was bended<br>-bearings were failed.<br>-screw blade was deformed.<br>-U-bolts were broken | -Adjustment<br>-Repair | -Repair<br>-Change |
| | | Pipes, lines and valves | 2 | -pipes and lines were worned out.<br>-valves were deformed. | -Tightening<br>-Repair | -Repair<br>-Change |
| | | Mill turbines and accessories | 6 | - shaft's thrust and radial bearings seats are worned out.<br>- unwanted gear back lash<br>-oil cooler pipes are worned out.<br>-operating and lubrication oil pressure under standard.<br>-admission valve problem<br>-governor problem<br>-tripping mechanism problem | -Inspection | -Repair<br>-Change |
| | | Transmission gears and accessories | 2 | -speed reduction gear worned out.<br>-unwanted gear back lash<br>-bearings failed.<br>-oil cooler pipes worned out. | -Inspection | -Repair<br>-Change |
| | | | | -vibration<br>-fan vane was damaged | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | Forced draft fan and accessories | | -bearings were failed | -Inspection<br>-Tightening | -Repair<br>-Change |
| | | Induced draft fan and accessories | 4 | -Vane drives and vanes were worned out.<br>-fan runners were damage | -Inspection<br>-Tightening | -Repair<br>-Change |
| | | Bagasse spreading and grit refiring system | 5 | -Vane drives and vanes were worned out.<br>-fan runners were damage | -Inspection<br>-Tightening | -Repair<br>-Change |
| | | Steam tubes worn out | 5 | -Checking generating | -plan to stop the unit. | -Welding |

**Resource**: From interview of MSF workers and Recorded data

Table 4.23 showed that mechanical failures were highly machineries down times in the factory. The causes of these failures discussed as follow.

In cane handling plant, cane unloader(hillo crane) work division activities, the causes of failure were worned out of components like; pulleys, bushings, hosting drum, rollers, hosting wire cable detached, pins sheared, driving motor and gear box alignment problem, bearings failed, frame bended, roller way and others. In cane tables parts, the causes of failurity were transport chain detached, chain link pin sheared, wearing of strips, drive sprocket teeth worn out and others were major causes. In cane carrier section the cause of failure were, chain link detached, pin worn out, drive sprocket damaged, bearing failed, bushing worn out and others were the source of failures. In cane cutters part, the cause of failures were, knives broken, drive bearings failed, vibration, structure cracked, knives domite tip worned out and the other were a factors.

Preventive tasks were inspection should be conducted as routine works, lubricating the units to minimize the failurity of components, re-greasing to minimize chance of failure of the components and changing. The remedies were repairing when the component failurity degree was minimum and if the units were damaged highly changed by others.

In milling section the units causes of failure were; tail bar couplings sheared, top roller scrapper adjustment bolts and its frame broken, rollers drive pinions worned out, under feed roller drive chain detached, under feed

roller drive sprocket teeth worned out, rollers teeth groove cracked or broken, delivery roller scrapper adjust bolts broken and others.

In mill turbine work division part; the causes of breakdown were shaft's thrust bearing seats worned out, shaft's radial bearing seats are worned out, driving gears worned out, oil guard worned out, turbine blade damaged, speed reduction tachometer pinions damaged, oil cooler pipes leaked, admission valve adjustment problem, governor adjustment problem, operating and lubrication oil pressure under standard, unwanted axial movement of the units, lybriths (steam guard) worned out and others.

In intermediate bagasse carrier part; failurity occurred due to slats broken and bended, strips worned out, bearings failed, drive sprocket worned out, bush bearings failed, drive chain link detached, drive chain pins broken and others. In pipelines, valves and tanks division work activities; causes element failures were pipes worned out, valves damaged, tanks were worned and other reasons were causes failure. Preventive tasks were inspection should be conducted as routine works, lubricating the units to minimize the failurity of components, re-greasing to minimize chance of failure of the components and changing. The remedy taken to the above failurity discussion was; repairing, changing, welding, grinding, and cutting the components according to the types of failurity.

To conclude the discussion above about cause of failurity of machineries very high and frequented. The main breakdown observed from Table 4.23 was the mechanical down time which affect the productivity of the organization. This came mainly due to poor maintenance strategy implementation in the factory.

**4.9 Production cost in MSF**

Profitability increase, as the most important business objectives, can be achieved through various savings. Many studies indicated that savings in maintenance always have the largest and direct value in all savings (Al- Najjar & Alsyouf, 2004). To monitor and to control maintenance cost, elements of maintenance cost have to be defined and linked to the corresponding maintenance operation. To produce sugar there were costs such as direct cost, indirect cost, overhead cost. The amount of total cost of 2019/2020 is taken from the annual report of the company as follow:

The present machineries maintenance tasks of the organization was breakdown maintenance. This maintenance strategy was highly implemented and maintenance cost was high. When compared maintenance performance of Metahara Sugar Factory for the worst year, 2019/20 among five years 576,154,477.22 birr while for the 2021/22 was 433,511,247.35 birr. This was a variation of 142,643,229.87 birr reduced due to the productivity value as shown in Figure 4.5 was 0.89.

In addition the productivity value of a year 2019/20 highest maintenance cost was as shown in Figure 4.5 was 0.83. This showed that the highest machineries breakdown as shown in Figure 4.6.

Figure.4.17 described that high maintenance cost of spare parts or material and employ wage cost. But the goal of the thesis was to minimize the breakdown time. The preventive and predictive maintenances should be applied in the factory to reduce maintenance cost.

**Table: 4.24** Maintenance cost of the company in 2019/2020

| The maintenance cost | **Cost in birr** | **Maintenance cost in %** |
|---|---|---|
| Employ wage | 217,422,292.52 | 37.74 |
| Spare parts or materials | 330,156,892.18 | 57.3 |
| Over time | 28,575,292.52 | 4.95 |
| Total cost | 576,154,477.22 | |

**Source:** Factory report

**Table: 4.25** Maintenance cost of the company in 2021/2022

| **The maintenance cost** | **Cost in birr** | **Maintenance cost in %** |
|---|---|---|
| Employ wage | 216,329,267.92 | 49.9 |
| Spare parts or materials | 183,131,403.17 | 42.24 |
| Over time | 34,050,576.26 | 7.85 |
| Total cost | 433,511,247.35 | |

**Source**: Factory report

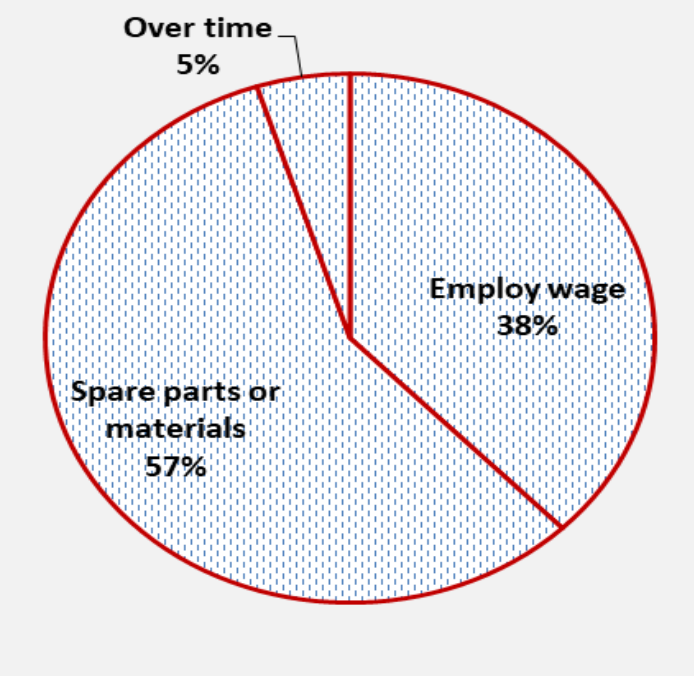



**Figure.4.17** Maintenance cost comparison of the company in 2019/2020

**4.10 Bottleneck of Machines and their Availability in Metahara Sugar Factory**

From table 4.26 the bottle neck machines in extraction plant were a milling a(ma), milling b(mb) and boiler plant(down times, due to mechanical and lack of steam down times) respectively which had high down times. So, these machines were critical and analyzing indicates the performance of sugar production.

From Table 4.26 the abbreviation were noted as follow:

Note: cha = cane handling plant a

mpa = milling plant a

chpb = cane handling plant b

mpb = milling plant b

mech.dt = mechanical down time

elec.dt = electrical down time

inst.dt = instrument down times

block.dt = blockage down time

other.dt = other down time

preve.maint.dt = preventive maintenance

pressure drop.dt = pressure drop down times

lack of steam.dt = lack of steam down time

**Table 4.26** 2019/20 Machineries down times

| | 2019/20 Cause of down times (hr.) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Plant** | **mech. dt** | **Elec.dt** | **Inst.dt** | **Block.dt** | **Other. dt** | **Prev.maint.dt** | **pressure drop dt** | **lack of steam dt** |
| 1 | CHPA | 307.8 | 79.25 | 0 | 233.38 | 1 | 0 | 16.75 | 41 |
| 2 | MPA | 590.03 | 82 | 0.5 | 233.38 | 0 | 26.5 | 131 | 41 |
| 3 | CHPB | 379.8 | 43.5 | 0 | 48.5 | 3.25 | 0 | 35.75 | 0.38 |
| 4 | MPB | 439.55 | 38.5 | 0.5 | 48.5 | 0 | 37.5 | 233.38 | 0.38 |
| 5 | Boiler | 413.13 | 10 | 2.25 | 3 | 1.5 | 0 | 44.67 | 0 |
| 6 | Pump and gear box | 35.75 | 2.75 | 0 | 1.25 | 0 | 0 | 12.75 | 0 |
| 7 | Process House | 15.75 | 0.75 | 0.25 | 3.25 | 0.5 | 0 | 14.7 | 66.5 |

### 4.11 Regression model for down time

Multiple Regression models are mathematical function that describes the relationship between one or more independent variables and responses or dependent variable. To create mathematical models for Total down time multiple regression analysis was used. Although multiple regression analysis is one of the most popular statistical tools to develop mathematical models for dependent variables, it is also one of the most frequently misused. There are assumptions that must be fulfilled, statistical tests that must be performed to evaluate the model's accuracy and the data's goodness of fit, as well as any issues that could arise with the model. How effectively analysts can use the methodologies to create suitable statistical models that are helpful to solve real problems is the first difficult. The second problem is figuring out how to use a good statistical software program, like Minitab, to implement the right methods and get the required output for evaluating and validating the proposed model. The regression models developed from collected data by Step wise regression in linear multiple regression models. The responses were written as a function of down time types like mechanical downtime (mech.dt), electrical down times(elec.dt), instrument down time(inst.dt), blockage down times(block.dt), other down time(other.dt), preventive maintenance down times(pre,mait.dt), pressure drop downtime (pressure drop.dt) and lack of steam down time(lack of steam.dt).

Based these down time types regression model's general equation can be written as:

$$Y = \beta_o + \sum_1^n \beta_i x_i \qquad (4.1)$$

Y is the response in Eq. (1), where $x_i$ was variables for (mech.dt), (elec.dt), (inst.dt), block.dt), other down time (other.dt), (pre,mait.dt), pressure drop.dt and (lack of steam.dt), respectively, and $\beta_i$, $\beta_{ii}$and $\beta_{ij}$ were the linear interaction factors. The number of control elements in this relationship can range from i=1 ton, with n equivalent to 8 in this case. The MINITAB® 17 Software was used to calculate the coefficients for multiple regression models using collected data. Regression equation was given in equation:

**Summary** of **report of for multiple regressions for down time (Dt):**

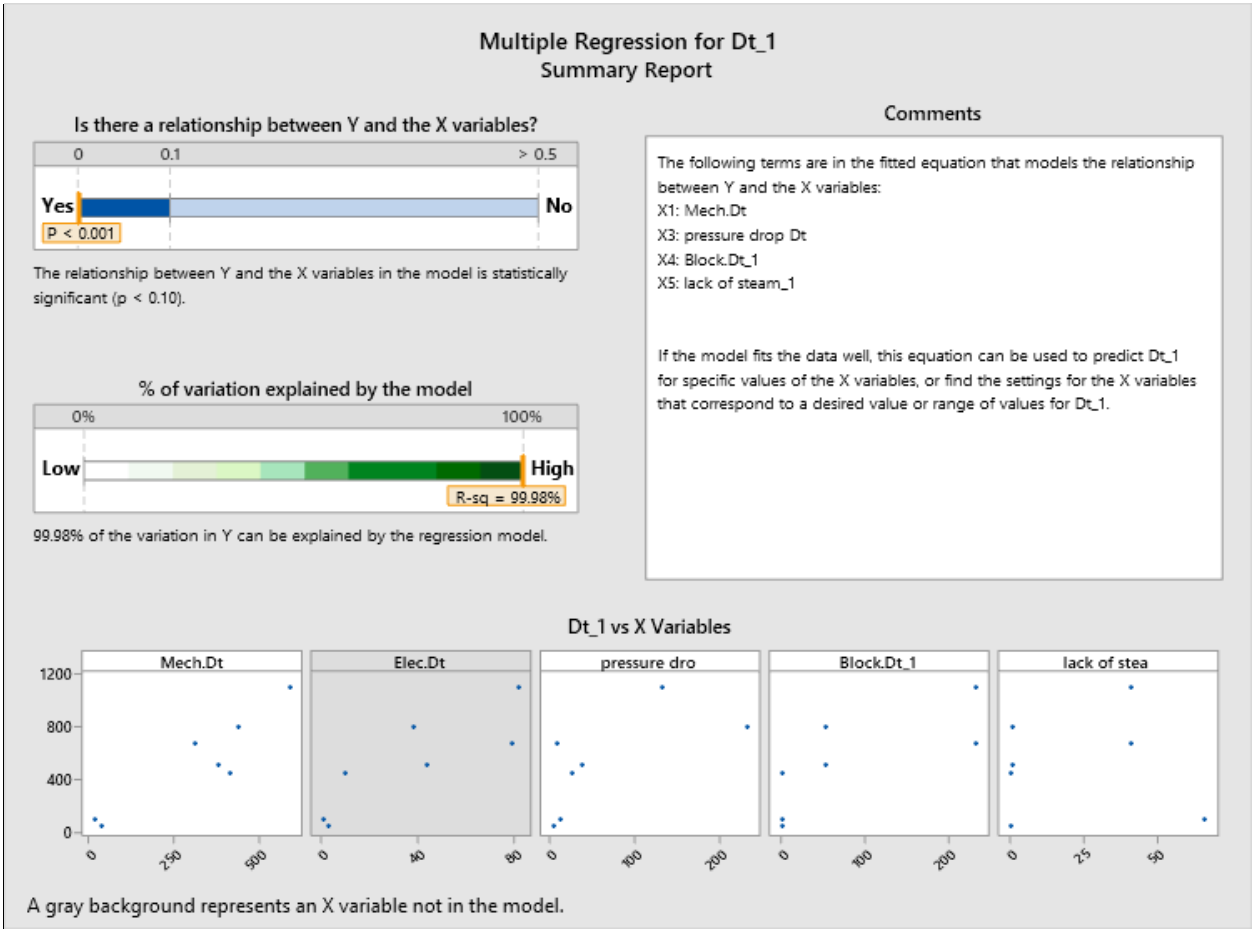



Figure 4.18 Summary report from Minitab software

Figure 18 described the summary report of the regression model is statistically significant with a P value less than 0.001 and has an R-squared value of 99.98%. The comments section indicates which variables were included in the model. In this case, the assistant includes (mech.dt), (elec.dt), (inst.dt), block.dt), other down time (other.dt), (prev.mait.dt), pressure drop.dt and (lack of steam.dt).

Figure 4.19 showed that the diagnostic report displays the downtimes versus fitted values and identifies unusual points that should investigated. Based on the criteria for large down times, expect roughly 5% of the observations to be flagged as having down times. So, the two had not necessarily problematic. There are also two points with unusual X values. Click the points to see which row was in the worksheet. The scattered graph showed that the parameters were significant.

DIAGNOSTIC REPORT:

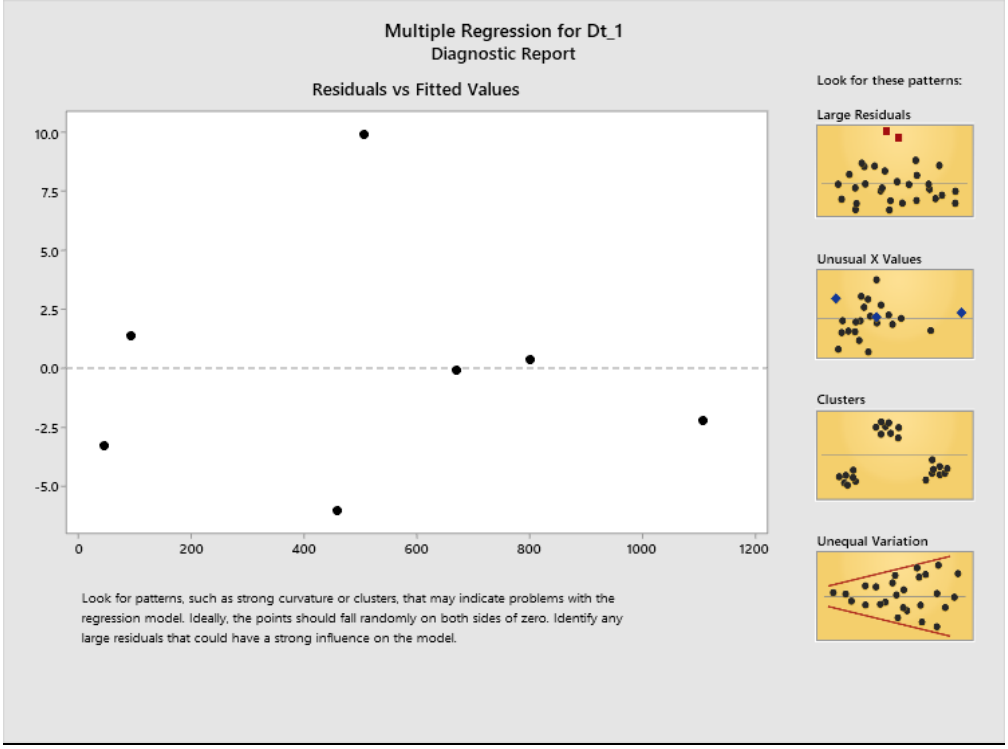



Figure 4.19 Diagnostic report from Minitab software

Figure 4.20 The model building report showed that the details about how the Assistant built the regression model, the regression equation, which variables contribute the most information, and whether the X variables are correlated with each other. Mechanical down time contributes the most information to this model. Electrical down time was not significant but the Assistant includes it because it is part of a regression term.

The generated down time equation was:

**Dt = 4.62 +1.0251X1+1.1914X3+1.3036X4+0.895X5** (4.4)

**Model Building Report:**

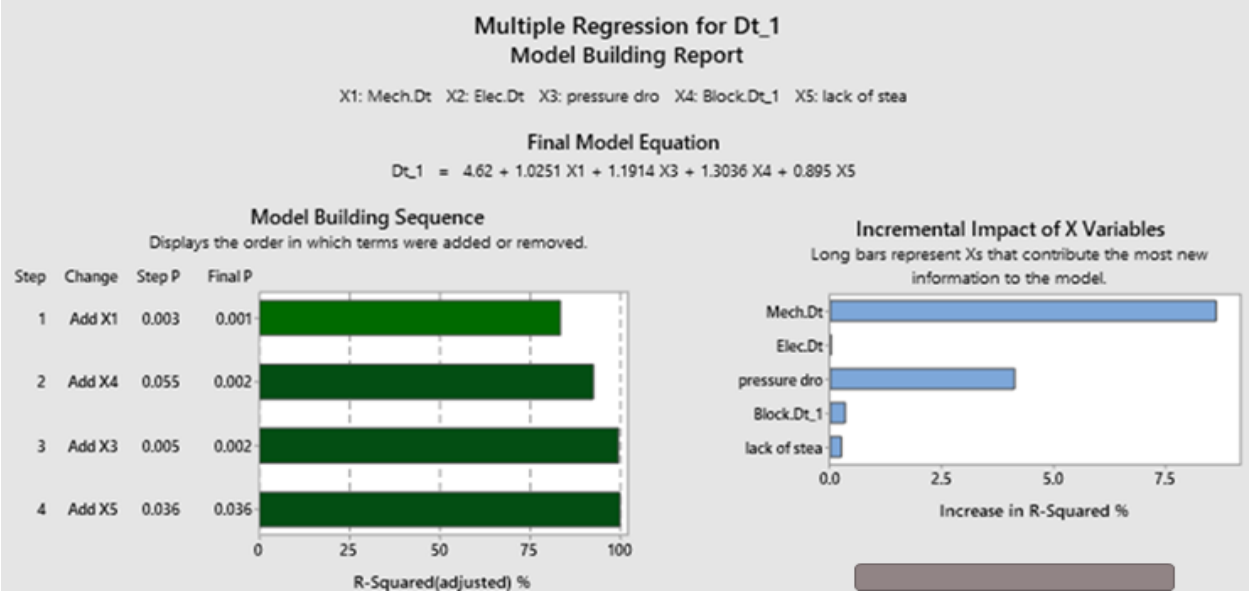



Figure 4.20 Model building report from Minitab software

Where: Dt = Down times

X1 = Mechanical down time (mech.dt)

X2 = Electrical down time (elec.dt) which was cancelled from equation due to insignificant parameter

X3 = Pressure drop down time (pressure drop.dt)

X4 = Blockage drop down time (block.dt)

X5 = Lack steam down time (lack of steam.dt)

Figure 4.21 showed that the prediction and optimization report assistant's solutions for obtaining the targeted value of 457.915. The optimal settings for the focal points were X1=413.13, X3=25, X4=0 and X5=0. This showed that the optimal point or targeted down time was 457.915hrs. The total down time in a year 2019/20 was 3721.83hrs which was the maximum down time among the five years down times and the efficiency of productivity was 0.83 from Figure 4.4 which smallest one. The optimized predicted down time value was 457.915hours which generated by Minitab software.

The productivity efficiency of the optimized down time which was 457.916 hours.

Calculated as follow: $\frac{A}{B}X\ C$

$P = \frac{457.916}{3721.83}X\ 0.83 = 0.102$. Then by multiplying by 100% which was 0.102x100% = 10.2%. This implies that the productivity will be increased by 10.2%.

**Prediction and Optimization Report:**

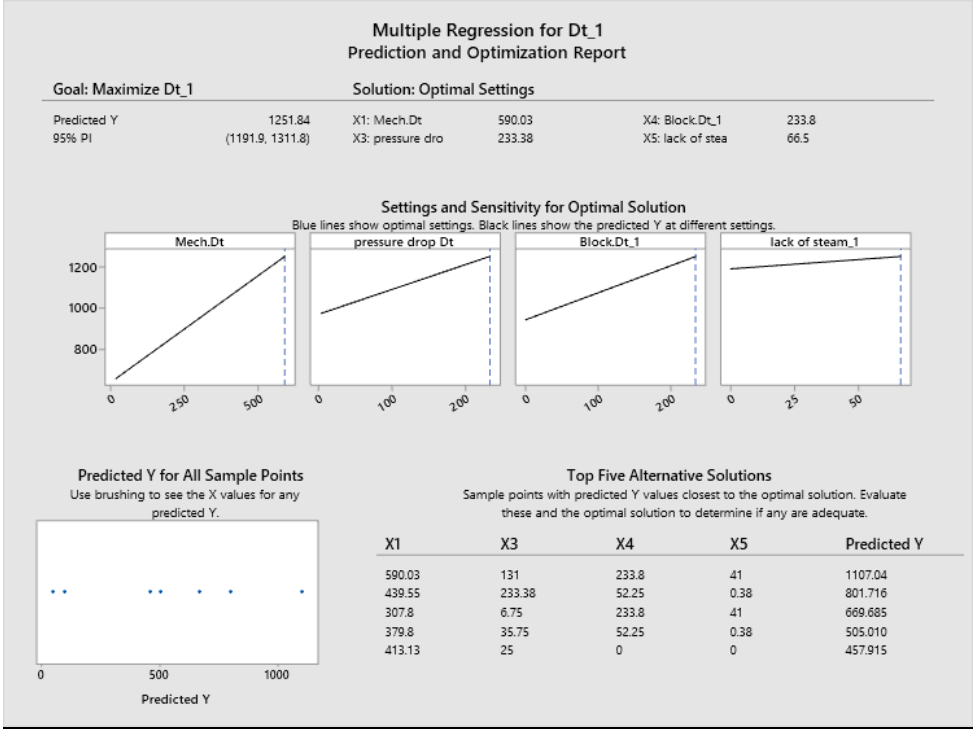



**Figure 4.21** Prediction and optimized report from Minitab software

Where: A = optimized down time (hrs.)

B = Total down time of 2019/20 campaign year (hrs.)

C = Productivity efficiency of 2019/20 campaign year

## 4.12 Maintenance work management

The job performed in maintenance departments of Metahara Sugar Factory (MSF) should be well managed to enhance productivity. In MSF the resources were limited and should be allocated in a systematic way to perform all the maintenance works according to planned time. It is a practice of the MSF to pass the preventive maintenance if the workers were occupied by corrective maintenance activity. But it is known that the preventive maintenance was very important and should be done according to the planned time to avoid or minimize the breakdown maintenance. Therefore, since the jobs were generated from two sources, from the planed and from the breakdown, should be managed based on the exists resources. To do these two maintenance tasks, the production and maintenance managers should have a common understanding about these activities. In MSF production department don't allowed any interruption during the production time to achieve set goal. So maintenance workers could not get time for preventive maintenance during the production

time. Thus, the production managers should be support and should understand the prevention activity to manage the planned jobs easily. The maintenance program should also consider the production plan during the plan.

### 4.13 Equipment Failure Management

Whenever machineries breakdown occur in MSF, the time required for repairing was too long. That affects productivity, because, unless the machines were repaired, no product was produced. Thus the main tasks of failure management were to minimize the repair duration. In MSF, usually, much of the time between the occurrence of the breakdown and completion of the repair was spent by analyzing the causes of failure of machines. Thus maintenance crew should be well trained on how differentiate and understand the work. Having the diagnostic device may be expensive for maintenance department, but the maintenance staff should work on inventing themselves to suit their particular situation. On the other hand spare part management is also one factor to shorten the repair time. Therefore, these four managerial functions were basic to generate a productive maintenance workflow. The procedures in which all maintenance activities should be clearly identified and known by all concerned bodies of the plant staff. Thus the duty and responsibility of production and maintenance managers, supervisors, planner, forman, operators, and the experts should be clearly identified and known by the company's concerned department. As it is seen from Fig. 4.3 the workflow of the existing maintenance department of MSF, several problems can be extracted. The activity was not planned to consider the corrective action. And also the spare parts were not ordered at the work planning stage, thus the downtime of the machine increases by waiting the spare part. Therefore, the workflow should be modified to alleviate the above stated problems. Thus, the modified workflow, which considers the above problem, is proposed below.

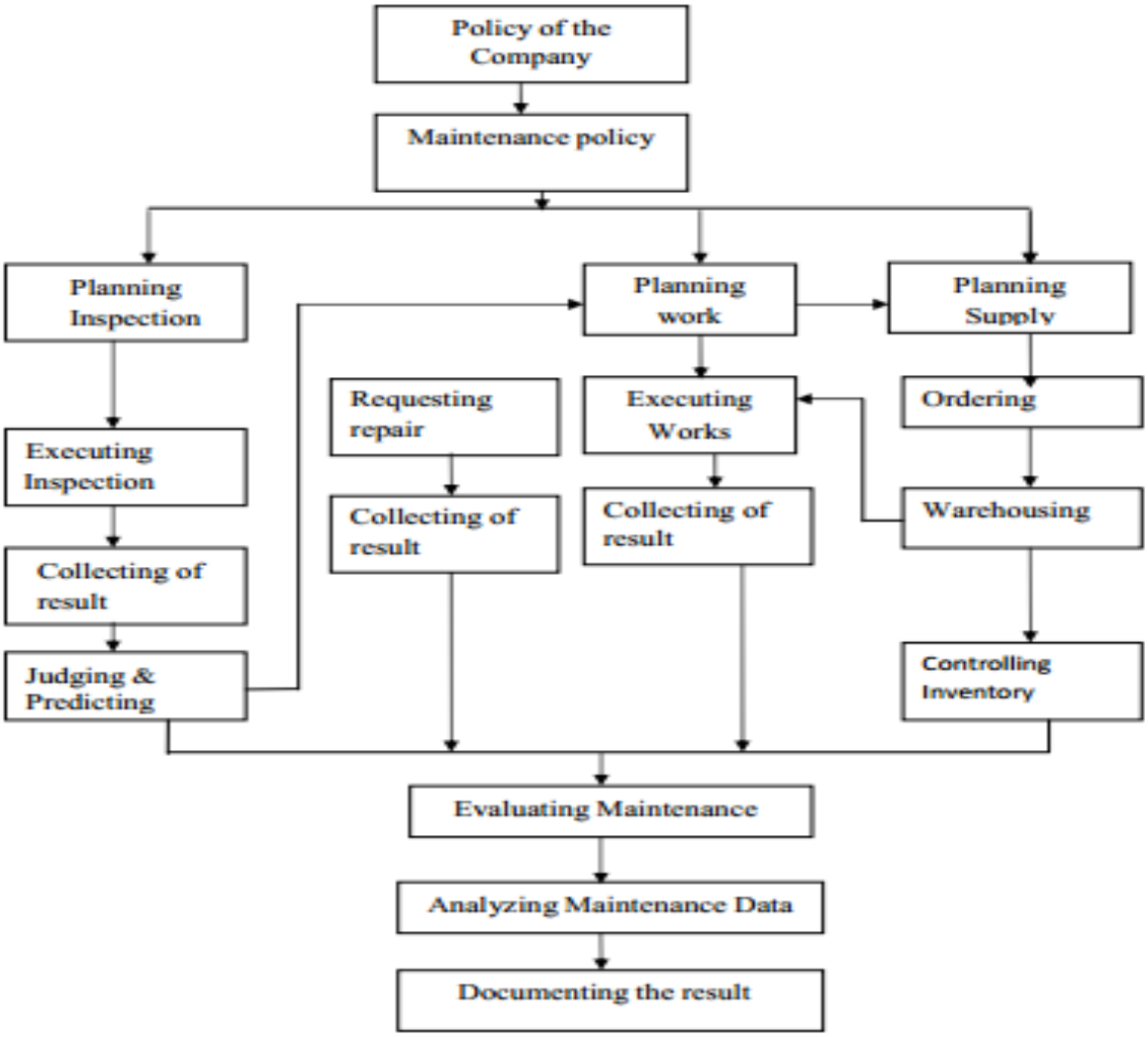



Figure 4.22 The proposed maintenance workflow (Ambaye,2011)

### 4.14 Future work

- With more information, the qualitative analysis of the scenarios should be further studied with quantitative analysis for a more refined methodology.
- With the new developments and innovations, other options to minimize maintenance costs should be studied.
- For critical machines or components the organization should install the sensors to detect the machines status before the failure occurred by considering costs.
- The updated technology and manufacturing system should be implemented to enhance the productivity by using more available resources.
- Failurity root cause analysis should be implemented to minimize machineries down time and enhancing productivity.
- Finally, implementation of the selected maintenance strategy preventive and predictive with detailed implementation guide and master plan will be highly recommended part of research.

# CHAPTER-5

# CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

In this, thesis work investigation of the maintenance strategy to improve productivity and the organization. As studied in this finding main problem of the factory was the high machineries down times which provided the decline of productivity and production. The major downtimes in the factory which highly affecting the productivity was mechanical and pressure drop down times as ranked respectively.

1. From the data analyzed the main plants which recorded high down times were cane handling, milling and boiler was investigated. The milling and boiler plants were the factory major bottlenecks.
2. From the survey of questionnaires results the problem of high machineries down times due to poor maintenance strategy implementation and there was no down time analysis tools, continues training not provide for workers, unavailability of spare parts were factors which provide machinery down times.
3. The performance result of the factory from 2017/2018 to 2021/2022 was 68,137.40tons, 63,311.20 tons, 595.10 tons, 76,266.60 tons and 44,472.60 tons of sugar respectively and the production plan was 97,175.10 tons, 95,000.00tons, 100,296.20 tons, 97,163.00 tons and 95,000.00tons for each year respectively. While the productivity calculated with ratio of sugar produced to cane crushed was 0.87, 0.848, 0.83, 0.89 and 0.89 respectively for the five consequentive years.
4. The productivity bottleneck of the factory were machineries downtimes in mechanical, electrical, instrument, blockage, others, preventive maintenance, pressure drop and lack of steam. Among total factory down time for 2019/20 year was 3721.83 hours per production year which was very high. The maintenance cost exposed for this year was 576,154,477.22 birr.
5. The maintenance cost analyzed between best and worst productivity campaign years. All mechanical, electrical, instrument, blockage, preventive maintenance, others, pressure drop and lack of steam down times were identified and analyzed and their impact were distinguished.
6. In current study to improve productivity multiple linear regression model was developed by Minitab software from factory down time data to predict the optimum value at which the productivity will be high by 10.2% profitability margin.
7. Finally, to achieve the optimized down time the organization should use the preventive and predictive maintenance strategy and rather breakdown maintenance which was highly used in the factory

## 5.2 Recommendation

Meahara Sugar Factory should be implemented the following recommendation to enhance the productivity.

- Since workers have high influence on enhancement of productivity, the continues training should be provided based on the current updated technology.
- Machineries spare parts should be bought according to the design specification and their quality. Especially, for critical spare parts purchasing priority should be given. Down times analyzer tools should be implemented to identify the machineries failure cause in detail.
- The preventive and predictive maintenance strategy should be implemented rather than breakdown maintenance, which is highly used in the factory.
- Machineries evaluation system should be used to know the status of the machinery or machinery components which help to take a maintenance plan on it.
- The organization should be allocated resources for maintenance because it is a determinant factors to enhance productivity.
- The organization should have a clear schedule for maintenance which is very important to minimize down times.
- The factory should have a policy to reject frequently failed machines because if it takes as a policy the workers mindset adjusted like as principles which has great impact on productivity increment.
- To know the machinery status, the organization should have maintenance key performance indicators.
- Preventive maintenance activities should be practiced in the company, as it is the better solution to increase the availability of equipments; the production department staffs also should understand preventive maintenance activities and should provide the equipment whenever needed.
- Due to poor implementing of preventive maintenance, the machineries not maintained within sufficient time because when machineries failed only running for breakdown which take more time to know root cause and maintaining. The cause analysis system should be implemented.
- The organization should practice the computer maintenance system to effectively control resource, like spare parts availability which used to know the amount in the store, to follow the workers skill status. The organization should apply overhaul equipment effectiveness key performance indicators to know the status of factory equipments.

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**APPENDIX A – Data of cane crushed and sugar produced from 2017/18 to 2021/22**

| S/N | Production year | Plan of cane crushed in tons | Actual of Cane crushed in tons | Plan of sugar produced in tons | Actual of sugar produced in tons | % cane crushed | % Sugar produced |
|---|---|---|---|---|---|---|---|
| 1 | 2017/18 | 919,517.80 | 741,048.40 | 97,175.10 | 68,137.40 | 80.59 | 70.12 |
| 2 | 2018/19 | 956,394.00 | 751,649.00 | 95,000.00 | 63,311.20 | 78.59 | 66.64 |
| 3 | 2019/20 | 988,817.00 | 897,191.20 | 100,296.20 | 75,595.10 | 90.73 | 75.37 |
| 4 | 2020/21 | 1,008,743.30 | 889,510.60 | 97,163.00 | 76,266.60 | 88.18 | 78.49 |
| 5 | 2021/22 | 1,008,743 | 526,781.70 | 95,000.00 | 44,472.60 | 52.22 | 46.81 |
| | Total | 4,882,215.40 | 3,806,180.90 | 484,634.30 | 327,782.90 | 78.06 | 67.50 |

**APPENDIX B - Down Time Data**

**Table B.1: Down time of 2017/18**

| S/N | Plant | Mech.Dt | Elec.Dt | Inst.DT | Block.Dt | Other Dt | Prev.maint. DT | pressure drop | lack of steam |
|---|---|---|---|---|---|---|---|---|---|
| 1 | CHA | 233 | 23.25 | 0 | 5 | 4.5 | 0 | 268.75 | 54 |
| 2 | MA | 394.5 | 9.5 | 4.5 | 13.75 | 31.5 | 27.25 | 268.75 | 54 |
| 3 | CHB | 298.45 | 32.5 | 0.5 | 26.75 | 8 | 0 | 59.5 | 5.25 |
| 4 | MB | 451.5 | 33 | 6.75 | 61.45 | 35.75 | 24 | 59.5 | 5.25 |
| 5 | Boiler | 410.75 | 18.25 | 2 | 1.25 | 4.75 | 48 | 0 | 0 |
| 6 | Pump and gear box | 41.5 | 22.5 | 0 | 3.25 | 3 | 0 | 0 | 0 |
| 7 | Process House | 15 | 0 | 0 | 0.25 | 2.5 | 0 | 0 | 37.75 |

**Table B.2: Down time of 2018/19**

| S/N | Plant | Mech.Dt | Elec.Dt | Inst.DT | Block.Dt | Other Dt | Prev.maint.DT | pressure drop | lack of steam |
|---|---|---|---|---|---|---|---|---|---|
| 1 | CHA | 142.65 | 4.25 | 0 | 5.25 | 5.25 | 0 | 405.88 | 18.75 |
| 2 | MA | 627.35 | 7.25 | 23.75 | 54.85 | 0.25 | 31.25 | 405.88 | 18.75 |
| 3 | CHB | 352.35 | 24.25 | 0 | 47.25 | 2.25 | 0 | 46.38 | 2 |
| 4 | MB | 363.25 | 25 | 1 | 184.25 | 4.25 | 31 | 46.38 | 2 |
| 5 | Boiler | 338.45 | 22.75 | 4.25 | 1.25 | 7.5 | 40 | 0 | 0 |
| 6 | Pump and gear box | 52.8 | 15 | 0 | 13.75 | 1 | 0 | 0 | 0 |
| 7 | Process House | 21.2 | 7 | 1.25 | 3 | 11.5 | 0 | 0 | 51 |

**Table B.3: Down time of 2019/20**

| | Plant | Mech.Dt | Elec.Dt | Inst.DT | Block.Dt | Other Dt | Prev.maint.DT | pressure drop | lack of steam |
|---|---|---|---|---|---|---|---|---|---|
| 1 | CHA | 307.8 | 79.25 | 0 | 233.38 | 1 | 0 | 16.75 | 41 |
| 2 | MA | 590.03 | 82 | 0.5 | 233.38 | 0 | 26.5 | 131 | 41 |
| 3 | CHB | 379.8 | 43.5 | 0 | 48.5 | 3.25 | 0 | 35.75 | 0.38 |
| 4 | MB | 439.55 | 38.5 | 0.5 | 48.5 | 0 | 37.5 | 233.38 | 0.38 |
| 5 | Boiler | 413.13 | 10 | 2.25 | 3 | 1.5 | 0 | 44.67 | 0 |
| 6 | Pump and gear box | 35.75 | 2.75 | 0 | 1.25 | 0 | 0 | 12.75 | 0 |
| 7 | Process House | 15.75 | 0.75 | 0.25 | 3.25 | 0.5 | 0 | 14.7 | 66.5 |

**Table B.4: Down time of 2020/21**

| S/N | Plant | Mech.Dt | Elec.Dt | Inst.DT | Block.Dt | Other Dt | Prev.maint. DT | pressure drop | lack of steam |
|---|---|---|---|---|---|---|---|---|---|
| 1 | CHA | 365.83 | 13.7 | 0 | 72.25 | 1.5 | 0 | 77.5 | 30.25 |
| 2 | MA | 399.04 | 13.25 | 3.5 | 77.79 | 6.75 | 26.75 | 77.5 | 30.25 |
| 3 | CHB | 437.04 | 33 | 0 | 29.5 | 5.5 | 0.75 | 12.13 | 2.25 |
| 4 | MB | 389.2 | 34.75 | 5.5 | 194 | 4.75 | 19.25 | 12.13 | 2.25 |
| 5 | Boiler | 354.89 | 6 | 2 | 3.5 | 3.25 | 13.5 | 0 | 0 |
| 6 | Pump &gear box | 30.25 | 1.25 | 0 | 9 | 0.25 | 0 | 0 | 0 |
| 7 | Process House | 25 | 0 | 2 | 8.25 | 2.25 | 0 | 0 | 49.75 |

**Table B.5: Down time of 2021/22**

| S/N | Plant | Mech.Dt | Elec.Dt | Inst.DT | Block.Dt | Other Dt | Prev.maint.DT | pressure drop | lack of steam |
|---|---|---|---|---|---|---|---|---|---|
| 1 | CHA | 174.25 | 4.25 | 0 | 17.95 | 0 | 0 | 45.25 | 14.5 |
| 2 | MA | 209.5 | 5.25 | 1 | 17.95 | 0 | 14.5 | 45.25 | 14.5 |
| 3 | CHB | 181.85 | 10.8 | 0 | 12.85 | 1.25 | 3.45 | 17.25 | 11.75 |
| 4 | MB | 288.5 | 3.25 | 3.25 | 17.25 | 0 | 0 | 17.25 | 11.75 |
| 5 | Boiler | 230.75 | 7.45 | 2 | 5.25 | 16.75 | 13.5 | 0 | 0 |
| 6 | Pump and gear box | 39.5 | 3.5 | 0 | 0 | 1.5 | 0 | 0 | 0 |
| 7 | Process House | 28.25 | 2.5 | 0.5 | 1 | 0 | 0 | 15 | 17.95 |

**APPENDIX C - Questionnaires**

**Adama Science and Technology University**

**Master of Science (MSc) in Mechanical Engineering**

**PART I: QUESTIONNAIRE TO BE FILLED BY RESPONDENTS**

**Dear participant:**

I would like to extend my deep appreciation if you could spend a few minutes answering the attached questionaries' as truthfully as possible will be highly confidential. The questionaries' are developed to conduct a Master's degree in Mechanical design and Manufacturing Engineering (MSc.) thesis research on an 'Investigation and Analysis of maintenance strategy in Metahara Sugar Factory to enhance productivity'. I would also assure you that all responses given will be treated as **Strictly Confidential**. And used for academic purpose only. So please try to answer all questions.

Thank you for your kind cooperation

Sincerely,

**Sultan Kasim**

Phone:+251-913947894

Email:gettk16@gmail.com

**Section I:** Personal Information

Please tick mark (√) under the choices you prefer for your priority.

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | Your gender | F ☐ | | | M ☐ | |
| 2 | Your Age | <24 ☐ | 25-35 ☐ | 36-45 ☐ | 46-55 ☐ | >55 ☐ |
| 3 | Educational level | Certificate-Diploma ☐ | Degree ☐ | Master degree and above ☐ | | |
| 4 | Work experience(years) | 0-5 ☐<br>6-10 ☐ | 11-15 ☐<br>16-20 ☐ | Above 21 ☐ | | |

**Section 2: Please put a tick mark (√) in the brackets that best describe your answer.**

After you read each of the statement, evaluate them in relation to your organization, and then put a tick mark (√) under the choices you prefer your priority.

Where, 5 = strongly agree, 4 = agree, 3 = Neutral, 2 = disagree and 1= strongly disagree.

| S. N | **Maintenance team** | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|---|
| 1 | There is high machinery failure in specific plan. | | | | | |
| 2 | Skill of Maintenance staff are well sufficient. | | | | | |
| 3 | The workers are continuously given training. | | | | | |
| 4 | The support staffs actively collaborate with maintenance technicians | | | | | |
| 5 | New employees were provided with the necessary training on maintenance before assigning to position | | | | | |
| 6 | On time resources were sufficiently allocated for maintenance | | | | | |
| S. N | **Machineries maintenance program** | | | | | |
| 1 | There is clear schedule for maintenance. | | | | | |
| 2 | There is shortage of spare parts for machineries. | | | | | |
| 3 | There are bottleneck machineries in the plant. | | | | | |
| 4 | There is a method to follow frequently failed machines. | | | | | |
| 5 | There is clear maintenance work flow. | | | | | |
| 6 | Shutdowns are planned for major repairs in advance. | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| S. N | **Maintenance evaluation** | | | | | |
| 1 | Sufficient evaluation mechanism for the performance maintenance exists | | | | | |
| 2 | maintenance key performance indicators are known | | | | | |
| 3 | Equipments maintained according to maintenance standard. | | | | | |
| 4 | During and after maintenance the maintenance activities checked by supervisors. | | | | | |
| 5 | Machineries spare parts were used as a standard. | | | | | |
| 6 | The equipment are maintained within sufficient time when the equipment failed. | | | | | |
| 7 | Technician regularly report actual working time, used material, and downtime on time. | | | | | |
| S. N | **Maintenance strategy** | | | | | |
| 1 | There was clear maintenance strategy in the industry. | | | | | |
| 2 | The preventive maintenance program done according to schedule and program. | | | | | |
| 3 | The maintenance program periodically review preventive maintenances for accuracy and training needs. | | | | | |
| 4 | The break down maintenance system highly implemented in the factory. | | | | | |
| 5 | The condition based maintenance system highly implemented in the factory. | | | | | |
| 6 | The organization tries to prevent breakdowns and failures. | | | | | |
| 7 | The organization have a schedule for periodic preventive Maintenance | | | | | |
| 8 | The organization has an inspection team to check the actual condition of equipment. | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| S. N | **Production volume** | | | | | |
| 1 | There is frequent machine downtime. | | | | | |
| 2 | Machine downtime minimize planned production capacity. | | | | | |
| 3 | Employees are encouraged to apply better methods when doing work after learning new skills. | | | | | |
| 4 | The production focuses on maintenance practice | | | | | |
| 5 | Decline of production has a huge impact on the Company. | | | | | |
| 6 | The level of machine downtime affects total production time | | | | | |
| S. N | **Machineries or equipments down time** | | | | | |
| 1 | There are high machineries down time in the factory | | | | | |
| 2 | The productivity is highly affected by machineries down time | | | | | |
| 3 | There are frequently failed machines in the factories. | | | | | |
| 4 | There are plants where machineries highly failed. | | | | | |
| 5 | There are machines components which provided high down time in the factory. | | | | | |
| S. N | **Method used to minimize machines failure** | | | | | |
| 1 | There is overall equipment evaluation calculated to monitor the condition of critical equipment | | | | | |
| 2 | The company has failure analysis conducted by the use of an analysis tool such as fishbone, Statistical Process Control (SPC) and others to assure accuracy and standardization for each analysis. | | | | | |
| 3 | You have a method which increases reliability of machines | | | | | |
| 4 | The organization believe that improving maintenance could increase the reliability of production system. | | | | | |
| 5 | The machines perform their required function for the specified time. | | | | | |

1. In the time of downtime which methods used to maximize production volume?

_____

_____

2. How you measure your maintenance efficiency?

_____

_____