# Addis Ababa University

# Addis Ababa Institute of Technology

# School of Mechanical & Industrial Engineering


## Overall Equipment Effectiveness Improvement through Implementation of Total Productive Maintenance: A Case Study on Dugda Construction Plc.

A Thesis Submitted to the School of Graduate Studies of Addis Ababa Institute of Technology, Addis Ababa University in partial fulfillment for the Degree of Master of Science in Industrial Engineering


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## DECLARATION

I hereby declare that the work which is being presented in this thesis entitled "**Overall Equipment Effectiveness Improvement through Implementation of Total Productive Maintenance: A Case Study on Dugda Construction Plc**" is original work of my own, has not been presented for a degree of any other university and all the resource of materials used for this thesis have been duly acknowledged.

______________________ ______________________

Muluneh Shibiru (Candidate) Date

This is to certify that the above declaration made by the candidate is truthful to the best of my knowledge.

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Dr. Ermias Tesfaye (Advisor) Date

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I express gratitude to the all-knowing, all-powerful GOD who provided me with everything I needed to begin and complete my work. Then my wife arrived, whose assistance I shall always remember. Then, I'd want to thank **Dr. Ermias Tesfaye,** my adviser, for his considerate and ongoing support of my work as well as for providing me with his expert advice.

My deepest appreciation also extends to all of the Dugda Construction Plc. workers involved in maintenance and production, particularly the batching plant operators, mechanics, and electrical technicians for their kindness in providing me with the data and information I require and supporting me without favoritism, as well as to all of my coworkers at my workplace who motivated me by offering helpful advice throughout the study period.

## ABSTRACT

*In the TPM literature, numerous frameworks for Total Productive Maintenance (TPM) pillars have been given proposed by various writers. However, the majority of them are based on research done in countries like Japan, Italy, the United States, China, and India. Thus, the aim of this study was to assess the contribution of a few TPM pillars to manufacturing performance in the construction industry. Data on production, downtime, reasons for downtime, and maintenance are gathered from the case company and analyzed to determine how the company's equipment is currently performing. Using a survey approach, 31 corporate employees were given questionnaires, with a 98% response rate being the end result.*

*The relationship between the manufacturing performance dimension and TPM Pillars has been calculated using descriptive statistical methods. In the survey, autonomous and planned maintenance received the most attention, whereas development management received the least attention. The TPM Pillars, autonomous maintenance, focused maintenance, planned maintenance, and training and education are all covered up in the report, despite their considerable contributions to manufacturing performance, including lower costs, greater equipment availability, strong delivery, and improved quality.*

*The results of the study indicate that the company's availability, performance, quality, and OEE were all increased by 67.74% 71.38% 99.08% 47.91%, respectively, as a result of the application of TPM. For the case company, a new implementation framework has been suggested. When completely implemented, all of the chosen pillars have activities that improve shop floor safety. Maintaining safety initiatives across all pillars will be crucial to creating a secure working environment.*



***Key words:*** *Total Productive Maintenance, OEE, Manufacturing Performance*

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## Acronyms

CM – Condition Based Maintenance

CFT – Cross Functional Team

FD – Focus Diagram

FGD – Focus Group Discussion

FMEA – Failure Mode Effect Analysis

JIPM – Just In time Preventive Maintenance

KMO – Kaiser - Myer – Olkin

MP1 –Cost

MP2- Quality

MP3 – Availability

MP4 - Delivery

OEE – Overall Equipment Effectiveness

PQCDSM – Productivity, Quality, Cost, Delivery, Safety, and Morale

SHE – Safety Health and Education

TPM – Total Productive Maintenance

TPS – Toyota Production System

UoM – Units of Measure

# CHAPTER ONE
# INTRODUCTION

## 1. Introduction of the research

According to Tsang et al. (1999), maintenance is the routine and ongoing process of keeping a specific asset or machine in its typical working condition so that it can provide the performance or services that are expected of it. Most manufacturers all over the world are choosing to use high-tech equipment as well as adopting non-traditional maintenance management techniques like Total Productive Maintenance, Reliability Centered Maintenance, and Condition Based Maintenance as a result of the forces of the global market demanding more emphasis on customization, quick delivery, and excellent quality.

Effective maintenance plan and strategy considerably increases the value of manufacturing activities and subsequent business, according to Bamber et al., 1997; Ahmed et al., 2005. Total Productive Maintenance is one of the well-known innovative maintenance strategies used by manufacturers (TPM). It was demonstrated to be one of the cutting-edge approaches to maintenance since it maximizes equipment efficiency, prevents breakdowns, and fosters autonomous maintenance through day-to-day operations and activities involving the entire workforce of the company. Since it was first presented a few decades ago, it has drawn interest from numerous businesses across numerous industries.

To mention about an overall equipment effectiveness (OEE) index, which combines the three criteria of availability, performance, and quality, is the primary statistic used by TPM to assess the efficiency of production facilities. Because it becomes a very important factor in automated flow line production systems that affect OEE. In fact, according to the TPM framework, the majority of downtimes linked to failures can be controlled, manageable, and decreased with an efficient maintenance action plan; quality loss continues to be an important source of inefficiency that necessitates a focused investigation. They are not connected to breakdowns or specific issues that call for the assistance of maintenance experts; production operators could manage and resolve them. However, they result in the major fault that prevents OEE improvement.

## 1.1. Background

Total Productive Maintenance (TPM), a tool for enhancing productivity and overall equipment effectiveness (OEE) of a machine, has been introduced by many industrial organizations from a wide spectrum in response to global competition and the need to increase the productivity of manufacturing and production lines (Goyal R, 2015).

When studying the development of Japanese maintenance practices, the period prior to 1950 is known as the "breakdown maintenance" period. The United States of America launched preventive maintenance in the 1950s, and in the 1960s, total productive maintenance gained popularity (Nakajima, 1998).

Ahmed T, Ali SM, Allama MM, and Parvez MS, (2010) claim that, the development of TPM started in the 1970s with the recognition of a single, true fact by management. TPM is essentially an enterprise-wide initiative to maximize the effectiveness and efficiency of any industry by performing preventive maintenance tasks continuously to reduce various failures and increase any types of machine availability.

Manufacturing management programs were created to support the development of industrial development at the period of Second World War, such as Just in Time (JIT) and Total Quality Control. Though, companies applying this program at their firms reported that a reliable quality product could only be assured with machines or equipment in good condition. Thus, equipment management began to be emphasized (Ogaji, 2004).

During the early days, companies were applying breakdown maintenance, which means that maintenance workers fixed equipment after it broke down (Shirose, 1992). This basic maintenance was unsuccessful and not effective in preventing some serious failures. The idea of preventive maintenance was introduced in the 1950s and recommended to users by equipment manufacturers (Ogaji, 2004). Records of equipment worsening also became important in reminding operators of the need to replace and repair damaged components (Xiaomeng, 2018).

Taking into account new demands in industry, the concepts of maintainability and methods improvement, and maintenance prevention were introduced. Methods improvement reduces the replication of the same issue, such as breakdown or fault; while methods planning refer to the design of equipment for convenient safeguarding. Methods enhancement and methods planning were added to preventive maintenance and incorporated into a new concept called “productive maintenance". By these approaches, companies could take advantage of the yield of their equipment processes (Shirose, 1992) (Xiaomeng, 2018).

In the 1970s, the concept of total productive maintenance began to be integrated into productive maintenance activities. Then, total refers to total employee participation, which implies "involving all the people in maintenance procedures" (Ogaji, 2004). Therefore, TPM evolved from productive maintenance into total productive maintenance.

**Background of the case company**

In order to play a key part in the Ethiopian construction business, Dugda Building Plc was found ed in 2011. The company provides clients with superior value-added services while utilizing the most recent construction techniques, technologies, and practices.

The company is on a fast road to growth and development thanks to the commitment of the mana gement team and employees as well as the supportive economic and political climate.

For all sorts of projects, including roads, power plants, industrial and office buildings, apartments, and etc., the company special foundation works can be used as deep foundation element which is cost effective and environmentally friendly product. The company general arrangement and organization of its management system is described in figure 1.1.

**Organizational Structure of the Company**

According to the figure below, it is appropriate to implement TPM in the organization as a whole. However, this research mainly focuses on the problem in the Plant and Equipment Administration and Maintenance Department. By implementing TPM, the research was focus on bringing the company profitability and productivity by eliminating the problem.

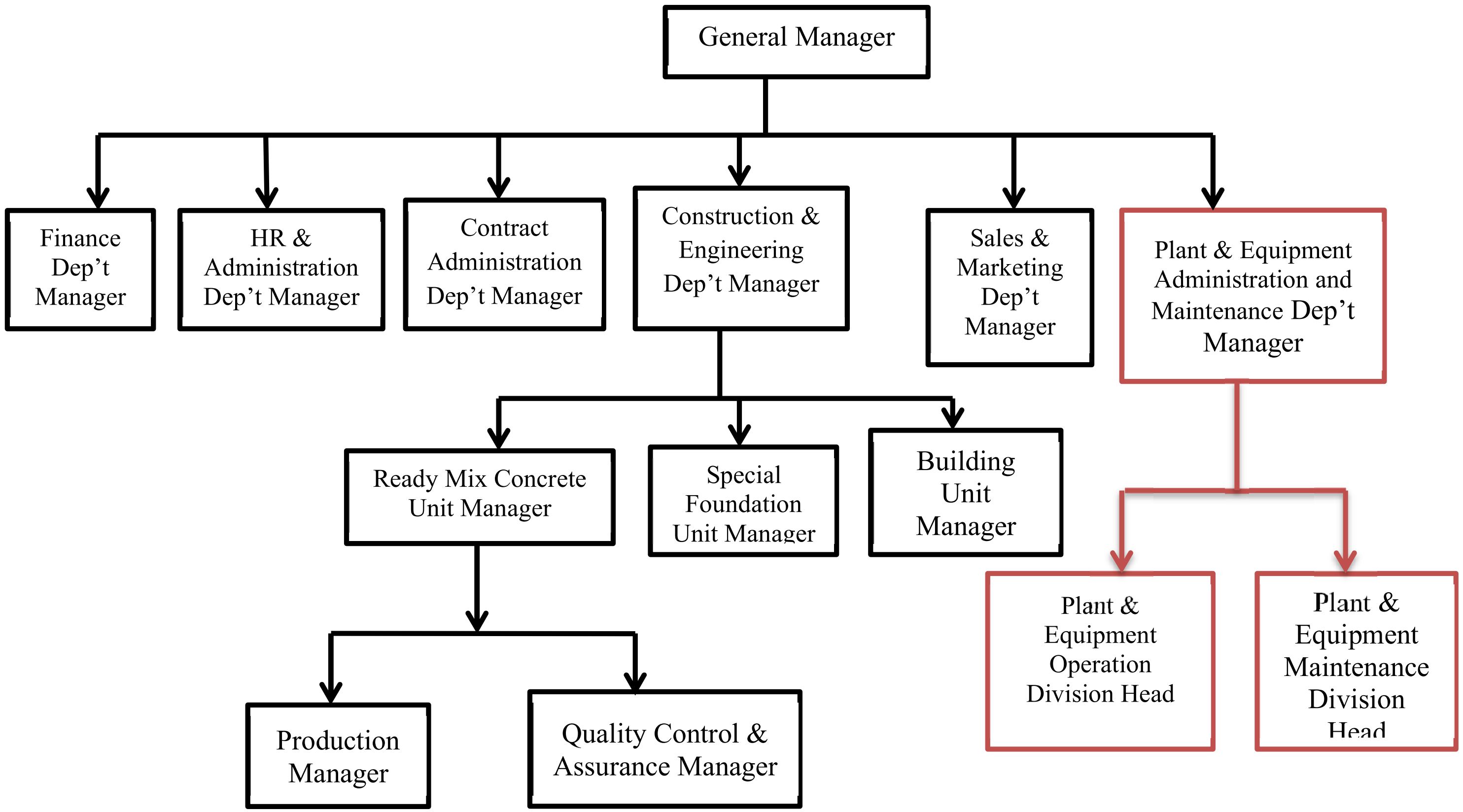



Figure: 1. 1: Organizational structure the case company currently available

## 1.2. Statement of the Problem

There is a high rate of machine breakdowns due to unplanned maintenance, sudden failure of main production equipment which was increasing the repair cost and machine downtime that leads to production lost in Dugda construction plc. This has brought the function of maintenance to be vital activity in the company in order for daily operation to become stable and effective. The company doesn't have any prior knowledge about preventive as well as predictive maintenance approaches.

Based on preliminary assessment made in the company there is no organized maintenance team committed to predictive as well as preventive maintenance instead a run to failure approach is followed for equipment sudden failures during normal operating conditions. The study was tried to select the major production equipment for TPM implementation that has a huge contribution for the production process. The Concrete Batching Plant, Excavator, Loader, Roller, Stationery Concrete pump, Truck mounted concrete pump, Cranes, Truck Mixers and Dump Trucks are the major ones. Frequent downtime has been happening in this equipment for more than a year. The plant has lost more production output due to these cases. For instance, if we take concrete batching plant production history record data.

Table 1. 1: The concrete batching plant production history record

| Date | Plan (m3/d) | Output (m3/d) | Design Capacity (m3/d) | Downtime (Hr.) | Remark |
|---|---|---|---|---|---|
| 1 | 900 | 510 | 1200 | 4 | |
| 2 | 900 | 720 | 1200 | 1 | |
| 3 | 900 | 680 | 1200 | 2 | |
| 4 | 900 | 850 | 1200 | 0 | |
| 5 | 900 | 595 | 1200 | 3 | |
| 6 | 900 | 510 | 1200 | 4 | |
| 7 | 900 | 0 | 1200 | 10 | Total Breakdown |
| 8 | 900 | 810 | 1200 | 1 | |
| 9 | 900 | 640 | 1200 | 2 | |
| 10 | 900 | 525 | 1200 | 3 | |
| 11 | 900 | 850 | 1200 | 1 | |
| 12 | 900 | 0 | 1200 | 10 | Total Breakdown |
| 13 | 900 | 0 | 1200 | 10 | Total Breakdown |
| 14 | 900 | 0 | 1200 | 10 | Total Breakdown |
| 15 | 900 | 800 | 1200 | 0 | |

Source; maintenance and production department

A preliminary assessment and practical problem observations show that there is a high rate of machine downtime and equipment failure occurring in the case company. This is due to a lack of planned and integrated maintenance and inspection strategy. Some literature explained that proper TPM implementation strategy could solve such machine frequent down times and under production of the equipment. But the research argues that only implementing TPM strategy cannot solve the cause for equipment downtime unless a special cross functional team shall be organized and trained to apply it practically. Furthermore, the company did not practice the philosophy yet for its maintenance programs. According to the plant & main equipment one year maintenance report April 1, 2021 up to March 31, 2022 show that 13,536 hours of machine downtime were recorded due to sudden failure and breakdowns. Due to this case the company has lost 11,733,185 birrs income. Therefore, based on the assessment made on the case company, one year production data and main equipment downtime history, the main cause for low productivity of production equipment and machinery is due to lack of maintenance system, specifically TPM. Hence, the research was tried to solve this problem through detailed analysis of the root causes and set an appropriate implementation plan.

Moreover, as shown in the table the plant & equipment annual report recorded that, the highest loss was plant break down than others factors affecting productivity. Hence, the researcher has focused on the plant and equipment was minimized break down using implementation of TPM.

Table 1. 2: reasons for losses of production in the batching plant

| S/No. | Description | | Unit measure hr. | Loss (birr) | % |
|---|---|---|---|---|---|
| 1 | Break down | | 13,536 | 11,733,185 | 87.44 |
| 2 | Idle time | Sand & Aggregate | 5 | 228,000 | 1.7 |
| | | Cement | 17 | 775,200 | 5.77 |
| | | Add mixture | 2 | 91,200 | 0.68 |
| | | Fuel Consumption | 9 | 410,400 | 3.06 |
| 3 | Defect product | Rework concrete ($m^3$) | 41 | 68,100 | 0.51 |
| | | Rejected product ($m^3$) | 28 | 112,000 | 0.83 |
| | | | **Total** | **13,418,085** | |

Source; quality, maintenance and production department from April 2021 to March 2022

## 1.3. Research Questions

Considering the practical problems occurred in the case company and reviewed literatures, the researcher summarized the following research questions for further explanation of the study:

1) How can the overall equipment effectiveness be improved in construction equipment?
2) What are the major causes for lower performance of construction equipment?
3) What are the impacts of TPM on overall equipment effectiveness in the case company?

## 1.4. Objectives

### 1.4.1. General Objective

The main objective of the study is to improve overall equipment effectiveness by implementing TPM at Dugda construction plc.

### 1.4.2. Specific Objectives

The specific objectives of the thesis include:

- To identify ways for OEE improvement in construction industry
- To find the major causes for lower equipment performance
- To identify the impacts of TPM on OEE in the case company

## 1.5. Scope of the Research

The boundaries of this study were focused on concrete batching plant, construction site and maintenance workshop only in time frame and limited maintenance and production data (the data was included from April 1, 2021 to March 31, 2022 as the time is limited to implement the TPM approach for only one year. The researcher decided to set such limited boundary considering:

- Which construction equipment and machineries are basic for OEE improvement of the whole company?
- The availability of data and resources which was helpful to conduct successful research

TPM is not a short-term program; it's a long and continuous approach to improve the construction equipment performance and productivity. Therefore, the researcher is planning to apply TPM on selected core construction equipment on a limited time frame and was continue the thinking on the other departments.

## 1.6. Research Organization

The research was consisted of five parts. The first part was the introduction that comprises the background, statement of the problem, research questions, research objectives, scope, limitation and significance of the study. It tells us the problem faced by the company because of not applying TPM, an introduction to TPM and purpose of the research. The second part was the literature review and definition of terms that presents the summary of the TPM method. In the third part the research methodology, design, sources of data and collection. In the fourth part, the collected data was analyzed using the appropriate and selected method of analysis. In part fifth, the finding of the study was discussed and a conclusion with recommendations of the researcher was explained.

## 1.7. Significance

The significance of the research is helping the company supervisors as well as department managers to investigate and solve the problems of TPM implementation and sustainability. Basically, the research has significant advantage for the case company to identify the root causes for poor machinery & equipment performances and improve the productivity and availability of main production equipment and also it has significant advantage to the scientific community to make further study in the topic.

Moreover, it helps to compare the theoretical as well as practical effectiveness of TPM implementation and performance. It is also used by various parties for a wide picture of how theoretical and engineering concepts are applicable in actual practice of organizations. Implementing TPM is promoted and positively changes the maintenance system for the whole company. TPM persuades operators to be engaged in the daily maintenance of machines and processes if successful TPM could be introduced to the whole company.

# CHAPTER TWO
# LITERATURE REVIEW

## 2. Introduction

This chapter's goal is to study the TPM literature, and it begins by reviewing the TPM approach concept. After that, a review of the literature focused primarily on TPM definition, history, objectives, maintenance kinds, OEE calculation, and maintenance in construction sector. The researcher cites the construction sector, Ethiopia's TPM history of success, and other sources.

### 2.1. Definition of terms

Productivity is an absolute measure that "states the relationship between what is produced in production and the efforts required attaining this" (Alexander, 1994). The following mathematical formula is used in the same literature to define productivity:

Productivity = (Output) / (Input) (Alexander, 1994).

The definition of productivity in the literature frequently relates to a manufacturing system's effectiveness. The second significant step in the evolution of a production system is productivity increase, as stated in the scientific literature (Bellgran & Safsten, 2010) (Alexander, 1994).

Depending on the kind of application that needs to be measured, the firms assessing productivity will specify the output and input. The article's author makes the following equation to illustrate how productivity may be boosted at all levels through better procedures, greater performance, and better utilization:

Productivity = Method (M) × Performance (P) × Utilization (U)

The terms "method" and "performance" relate to the expected productivity rate, "utilization" is the actual time spent relative to the total planned time, and "performance" is the speed at which operations may be completed in comparison to the ideal cycle time. One may quantify the present productivity obtained from the current operations by precisely defining these three parameters, and by optimizing the same factors one can boost productivity for operations in production system. 2012's Almastrom. The following is a different, more condensed definition of productivity that can be found in the literature.

According to Antonio Frieser, (2020), Industrial maintenance is a key stage in any production process. Productivity can be defined as the relationship between productive activity and the resources required to carry it out. These methods may involve infrastructure, people, or technology. In order to achieve the highest levels of efficiency in a society where outcomes are the determining factor in success, it is also important to grasp how this relationship between maintenance and productivity works when discussing industrial maintenance. The study reveals that there is a strong relationship between productivity and industrial maintenance. Any company's primary goal of productivity shouldn't be disturbed. But when there are machines, technologies, and human resources involved, things can happen. So what do you do? The key is in the upkeep and management of it. A good maintenance management strategy puts productivity first, tries to achieve the highest levels of asset availability, and avoids at all costs cutting back on production resources. Therefore, the productivity will depend on the link between the reliability rates as a result of maintenance process management and the resources required.

## 2.2. The importance of maintenance

"Most organizations do not realize the cost of downtime their equipment and what the total financial effect of useless machinery is on their business," the Department of Trade and Industry (DTI; 1988) stated. The report's conclusion emphasized the need for a shift in management perceptions of maintenance and the need to incorporate maintenance into the production plan.

Plant and equipment maintenance is a vital issue in any manufacturing sector. (Alam, Md.Aminur Rashid and Rabiul., 2016) suggested that the implementation of TPM requires more time, resources and efforts; it can be difficult to carry out all the pillars of TPM at a time to achieve the desired output and also can be a big challenge for the company to roll out TPM since there may be other existing practices. (Wardhani, 2019), also suggests that the goal of TPM is to improve the company's structure in terms of materials, equipment, tools, machinery, raw materials and products and also in manpower terms.

According to (Sivakumar Annamalai, 2019) before applying TPM to an organization it is better to set good information and knowledge sharing and a special steering committee appointed for the successful test.

The effectiveness of the equipment immediately affects the productivity of the production processes, has an impact on the productivity of the workforce, and helps to ensure the quality of the final product and customer satisfaction. (Gupta P, et al. (2016).

In order to design a maintenance target that is consistent with their manufacturing strategy, maintenance managers and his subordinate should take into account the levels of maintenance that are required for their specific production situation. An expensive non-competitive scenario may emerge from failing to design an effective maintenance strategy.

## 2.3. Maintenance Practices

Because the TPM idea is more closely associated with for all manufacturing sector, applying it is one of the best ways to overcome OEE levels below 80%, thus its use in the healthcare service sector is novel. The sincerity of every person engaging in TPM activities, from employees to management, is crucial to the success of the implementation. Discipline in following established processes and maintenance recommendations will be quite helpful in achieving each TPM pillar (H. A. Prabowo, et al (2018).

Overall equipment effectiveness is a crucial factor in determining if TPM is successfully implemented inside a company. According to Goyal R, Jindal S, (2015), in order to increase equipment productivity, efficiency, and effectiveness, the factors such as reducing manufacturing cycle time, customer complaints, and handling autonomous groups on their abilities and confidence levels have to be addresed.

Due to the standardization of work and processes based on the three primary pillars of TPM focused maintenance, autonomous maintenance, and scheduled maintenance TPM deployment can result in additional non-economic benefits including better safety and convenience of repairs (J. D. Morales Méndez and R. S. Rodriguez, (2017).

Lean manufacturing's primary goals are to reduce cycle times and remove waste in order to boost profits, productivity and competitiveness by boosting output and lowering costs.(Nallusamy, S. and Saravanan, (2016).

In order to improve manufacturing productivity and to measure by using overall equipment effectiveness (OEE) in an Ethiopian boiler plant, (Wakjira and Singh's study from 2012) established connections between varieties of TPM aspects. The study identified improving performance enhancements as one of the key TPM success elements.

(S., 2019), assessed the contribution of a few TPM pillars on the manufacturing performance at the Nile Sole Factory. In order to conduct the study, the company provided data on production, downtime, causes for downtime, scrap level, and rework, which were then gathered and analyzed to determine the company's present performance and production output. According to the study, five of the eight TPM pillars focused improvement, planned maintenance, autonomous maintenance, and training and education made a significant impact to the specified manufacturing performance metrics, including cost, availability, delivery, and flexibility.

## 2.4. Types of Maintenance

According to (Al-Najjar, 1996), Albert (2000), Graisa and Al-Habaibeh (2007), there are primarily three major types of maintenance: unplanned breakdown maintenance, planned scheduled maintenance, and condition monitoring-based maintenance (CBM). Unexpected machine failure and unplanned maintenance have a significant impact on the production system's efficiency since they increase downtime and add unanticipated expenditures. However, planned scheduled maintenance is typically based on any machine maintenance suggestions and statistical analysis of past machine failure data history. The condition monitoring based maintenance approach is a scheduled maintenance that depends on monitoring and evaluation the vital machine parts while they are in use. The analysis of the condition monitoring data can be done to estimate the failure time which will further allow maintenance to be planned (Qin and Tang, 2005, Juan, 2009 and Rosqvist et al., 2009. By optimizing preventive maintenance planning, strategy and maintenance operation efficacy, condition monitoring helps reduce breakdown costs.

Table 2. 1: The Philosophies of Maintenance Development

| **1900 through the present days** | **Characteristics of the tool** | **Maintenance Philosophy** |
|---|---|---|
| First-generation upkeep (1900-1939) | • Equipment is basic and straight forward to fix. | • Basic and regular upkeep<br>• Reactive maintenance, only fixing problems as they arise |
| Second-generation upkeep (1945 -1979) | • Equipment is increasingly complicated, and industry i s more dependent on it.<br>• Maintenance expenses are more expensive than other operating expense | • Preventative maintenance that is planned<br>• Time-based strategy<br>• Total Productive Upkeep (TPM) total involvement of the workforce.<br>• The maintenance process is team-based and looks at culture and people rather than systems. |
| Third-generation upkeep (1980s – Present) | • The complexity of the equipment<br>• The accelerated use of automation<br>• The high cost of downtime<br>• The desire for higher-quality items from customers | • Condition monitoring (CM), hazard studies failure modes and effect analysis (FMEA)<br>• Reliability-centered maintenance (RCM)<br>• Examination of the machine or system<br>• Computer-aided maintenance management<br>• Workforce with a variety of skills |

(Source: Sherwin 2000; Waeyenbergh and Pintelon 2002)

## 2.5. The Significance of Maintenance in Equipment Effectiveness

The competitive business strategy for many organizations to be the best in the market in their sectors is characterized by the strong emphasis on efficiency, delivery, and quality in both large and small factories of today's global companies. Manufacturers use cutting-edge machinery to meet these standards. They are also using fresh approaches to material management, such as the just-in-time (JIT) philosophy, which advocates for continuous production systems that don't require inventory setup and that require the least amount of modification time.

Due to these circumstances, businesses are being forced to divert their attention to maintenance since unplanned machine downtime causes serious issues (Hayes and Pisano, 1996; Christian et al., 2009). As (Blanchard, B., 1997) noted, current trends show that the introduction of new technologies is generally leading to an increase in system complexity.

However, they fall short of client expectations in terms of effectiveness and performance; in addition, system costs are rising in comparison to their operation and maintenance. As a result, even if the cost of maintenance can be considerable, it is now more important than ever to regulate the equipment in order to meet the needs of the production line and maintain competitiveness in the market. The efficient operation of commercial organizations today depends on equipment maintenance and dependability management, claims it to design proper maintainability and reliability plans due to the rising reliance on technology for the bulk of corporate operations to ensure that these organizations can deliver high-quality and dependable services to their consumers (Gunaskeran, A., 2008).

The operation's function of maintaining the machines is essential, and a good and efficient maintenance strategy can considerably add value to the production activities. Manufacturers ought to view and evaluate maintenance as a world-class principle. Manufacturing companies aiming for world-class performance have demonstrated that a good maintenance strategy may play a significant role in improving competitiveness (Bamber et al., 1999; Al-Najar, 1996).

The desired product is the production's most crucial output. The requirement for maintenance, on the other hand, is a supplementary output that serves as an input for the maintenance function. Production capacity produced by maintenance serves as a supplemental input to the final product. Maintenance creates the capability for manufacture, whereas production creates the product. Therefore, by increasing production capacity and managing output quality and quantity, the impact of maintenance on production may be realized. In an organization that works in tandem with production to maintain the production flow, maintenance is a crucial function. Manufacturers should view maintenance as a core activity that requires strategic planning in order to receive continuous production from machinery and equipment. According to (Ollila, A. and Malmipuro, M., 1999) and (Yamashina, H., 2015), the increasing competitive power of the company depends on the development of advanced manufacturing engineering to set up a suitable production process that necessitates brilliant maintenance procedures so that equipment is always available whenever needed and produces products with the necessary level of quality. Long-term maintenance should be considered a crucial component of an organization's strategy.

According to the organization's capability and resources, maintenance should be scheduled sensibly and realistically. By lowering unplanned failures and faults, the clear development of maintenance and application is assisting to improve equipment reliability and availability, and this is help to supply the market with products that are of high quality and low cost.

## 2.6. Total Productive Maintenance

The proper and effective utilization of the operational and human resources available for the manufacturing process is one of the major issues encountered in the industrial setting. High productivity in continuous production systems is prioritized through effective resource allocation and operational processes. However, the effectiveness of such production systems' key processes, or "bottlenecks," directly affects productivity (Moellmann et al., 2006; Moraes and Santoro, 2006).
TPM seeks to continuously enhance an organization across all facets. According to the aforementioned references, a full definition of TPM comprises the following five TPM objectives:

a) Overall Equipment Effectiveness (OEE) is the goal of TPM;
b) TPM develops a rigorous preventative maintenance program throughout the duration of the equipment's life;
c) a number of departments (engineering, operation, and maintenance) implement TPM;
d) Every single person, from top management to staff, is involved in TPM; and
e) TPM is based on the motivation-based promotion of preventative maintenance.

By putting the employee at the center of the maintenance and production strategy, the TPM program's goal is to greatly boost output while also improving employee morale and job satisfaction.

According to (Maggard, B. and Rhyne, D., 2019), total productive maintenance (TPM) is widely used because it integrates production and maintenance functions but more importantly, it redefines the roles of the operators and maintainers, thereby empowering the workforce, which should be at the center of any change in maintenance activities. According to Pintelon (1999), implementing TPM in a short period of time is unfeasible since it requires careful preparation, adequate management backing, and funding approval.

Figure 2.1 explains what Total Productive Maintenance is in general terms. TPM encompasses all departments, removes all machine issues, and includes all people. Production and maintenance are linked, and issues are reduced or removed. Preventive maintenance and Condition-Based Maintenance (CBM) are used to keep machines in top operational condition.

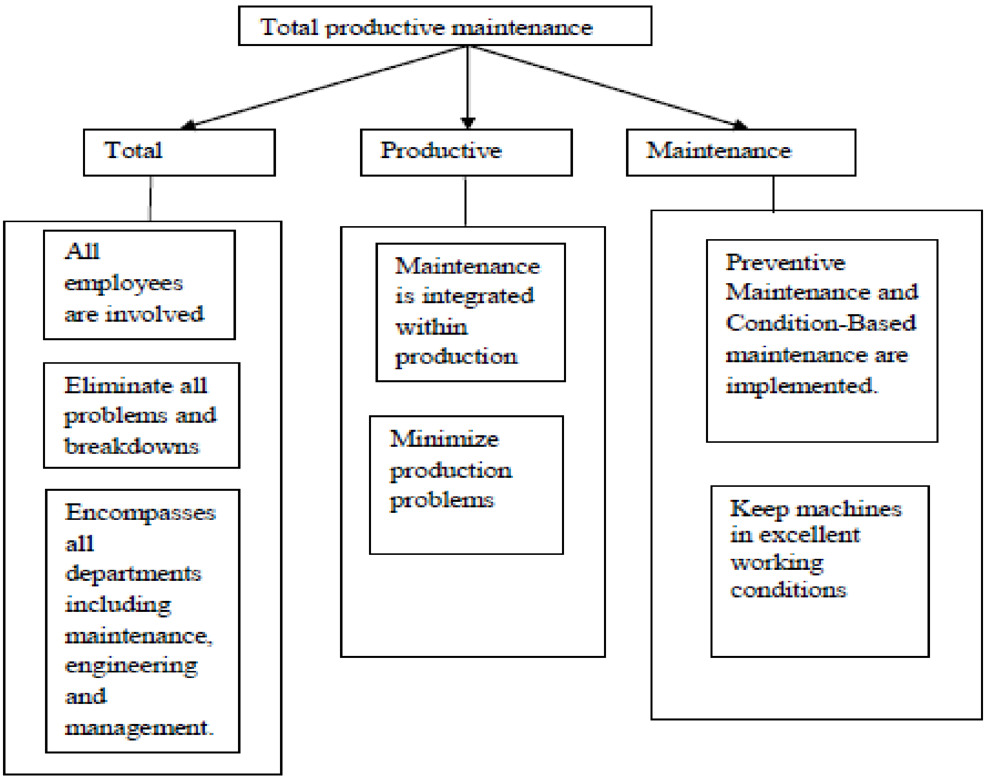



Figure 2. 1: Definition of Total Productive Maintenance (Graisa, M., 2007)

TPM, according to Maggard and Rhyne (1992, quoted by Lawrence 1999), essentially combines production and maintenance functions with the purpose of increasing equipment reliability, minimizing downtime, and cutting waste. Examples of the effectiveness of TPM have claimed to boost labor productivity by 100%, reduce waste and rework by 75%, and minimize downtime by up to 80% (Labib 2000; Tsang 1998; Cooke 2005 and Shad 2008).

Total Productive Maintenance (TPM) is a well-known technique that attempts to increase equipment dependability and efficiency rates, get rid of faulty wastes, limit process fluctuations, and lower production costs, according to Chan et al. These goals can be met by determining the causes of failures and downtimes, extending the time between failures (Mean Time to Failure), and involving and empowering employees at all organizational levels (Ireland et al 2001 and Blanchard 1997). According to McKone et al. (2001), TPM improves manufacturing performance by strengthening a company's ability to recognize and address issues. TPM also helps to promote organizational culture and break down traditional departmental barriers between maintenance and production personnel. The elements of the TPM system, according to Bamber et al. (2000) and Ahmed et al. (2005), are as follows:

**1- People development:** The fundamental goal of TPM now is to train and develop individuals. Well-organized and planned training programs must be accessible, say Prouty (2006) and Mouss et al. (2004), in order to guarantee that workers have the necessary levels of knowledge and skills to increase performance. In order to reduce unneeded equipment downtime and increase production, people need receive proper training (Binninger, 2004).

**2- Documentation:** Monitoring, controlling, and maintenance actions should be properly documented and recorded.

**3- Regular maintenance:** Scheduled and planned routine maintenance on equipment with the goal of lowering breakdown rates and improving equipment use. TPM emphasizes that implementing a systematic maintenance plan is a crucial step that plays a crucial part in businesses. The importance of normal maintenance tasks including inspection, tightening, lubricating, and cleaning within the preventive process of failures and faults that may be brought on by malfunctioning equipment has been highlighted by Bris et al. (2003).

**4- Housekeeping keys:** Putting the five-sigma principles of housekeeping into practice to enhance the interior environment the housekeeping functions (5S) can be enumerated as follows, according to Eti et al, 2004.

a) **Sort (Seiri)** - locating the tools and materials required in the workspace,
b) **Straighten (Seiton)**- The working space should be cleared of extra tools and materials.
c) **Sweep (Seiso)** - Regular upkeep and cleanup duties must be carried out in the workspace.
d) **Standardize** (Seiketsu)- Work and process should follow established, documented standards, and;
e) **Self-discipline (Shitsuke)** - By putting the aforementioned procedures into practice and integrating them into daily tasks, discipline standardization can be achieved.

When preventive maintenance was first used in Japan in 1951, TPM was born. Yet, the USA is where the concept of PM is originated. In 1960, Nippondenso became the first business to implement preventive maintenance across the entire facility.
With the automation of Nippondenso, maintenance became a concern because more maintenance employees were needed. Preventative maintenance is the idea where operators produced things using machines and the maintenance group was dedicated to work on maintaining that equipment. Hence, the management decided that operators would be responsible for performing routine maintenance on the equipment. One of the features of TPM is autonomous maintenance, which is what this is.

To increase reliability, the maintenance team modified and corrective maintenance the equipment. The alterations were made or applied to new machinery.
Preventive maintenance, together with Maintenance prevention and Maintainability Improvement, gave rise to productive maintenance as a result of this leading to maintenance prevention. In order to obtain the best life cycle cost for production equipment, productive maintenance aimed to maximize plant and equipment effectiveness and reducing maintenance costs.
TPM was developed in Japan in 1971 as a mechanism for boosting machine availability and productivity by more effectively using production and maintenance resources. (Agustiady & Cudney, 2016) state that the goals and advantages of TPM are to improve top management commitment, job satisfaction through the reduction of damage, decreased quality issues, decreased safety / environmental incidents, reduced costs, increased throughput, competitive advantage, and minimized emergency maintenance and unplanned.( Agustiady, T. K., & Cudney, E. A. (2016).
A successful and effective program and a novel idea adopted into the equipment maintenance plan is total productive maintenance (Sethia et al., 2016).
The TPM strategy has an effect on the company's business and enables the manufacturing system to improve optimal output. This method, which is employed in all organizations and is constantly evolving, can enhance the crucial business procedures required to establish key performance indicators (Nishal et al., 2018).
Total Productive Maintenance (TPM) emphasizes maximizing equipment performance, establishing a productive maintenance system that optimizes its life cycle, contributing to ongoing availability and improvement, avoiding early equipment wear, and being necessary that the maintenance work on preventing with managerial focus (Meca Vital & Camello Lima, 2020).
The average waiting time between failures can be lowered from 13 hours to 7 hours with the proposed maintenance process simulation, which results in a 15% reduction in downtime. And a 90% increase

in time that is available. (Palomino-Valles, A., (2020). The stamping machine's OEE value is still poor since reduced speed loss (53%) is the main cause of all-around downtime. (Herry, A. P., Farida, F., & Lutfia, N. I. (2018).

A reduction in maintenance expenses of 16%, a reduction in downtime in the plant of 35%, and an i ncrease in machine availability of 784 tons annually all followed the installation of TPM. (Gallesi-Torres, A., (2020).

The Nippondenso Industry, a supplier of electrical components to the Toyota Motors vehicle company, might be credited with starting Total Productive Maintenance (TPM). He quickly understood that by implementing and refining the Toyota Production System, Toyota had already enhanced their working procedures (TPS). According to Ohno (1978), a system was being developed for "the total eradication of waste." Toyota's production increased along with their need for replacement parts, and soon supply couldn't keep up with demand. Nippon's senior management made the decision to track a variety of metrics, including output per hour, lost time from machine breakdowns, and defect rates (Yamashina 1995; Anish et al., 2008).

TPM does this by valuing collaboration, reaching consensus, and ongoing improvement highly (Moore and Rath, 2000). The 1970s and 1980s saw the gradual development of TPM as an organizational-wide initiative as businesses in Japan began implementing this strategy as a fundamental maintenance philosophy. As its remarkable advantages and benefits became recognized, the notions of tool maintenance underwent a paradigm shift from "I operate you fix it" to "it is my machine, I operate and maintain it" (Hokoma, R., Khan, M. and Hussain, K, 2008). Cooke (2000) claims that TPM combines strong working methods, teamwork, and continuous improvement to perform both the production and maintenance functions simultaneously.

According to Labib (2000), the goal of TPM is to bring maintenance and production together in small groups so that they can share knowledge and carry out specified tasks. This action aids in locating maintenance issues and offering solutions. The concept of zero faults in Total Quality Management (TQM) is the foundation of TPM. It can be applied to machinery to help reduce breakdowns and minimum production loss and improving machine efficiency (Goto, 1991; Ahuja and Pankaj, 2009). The goal of TPM was to keep machinery in good functioning order, increase its useful life, prevent breakdowns, and minimize, if not completely eliminate, unscheduled stoppages. On the other hand, this can only be accomplished if senior management's dedication is apparent to all employees.

TPM is not a temporary remedy. It must be viewed as an ongoing process that enables maintenance activity to be highlighted as a crucial and necessary business function. Organizations might schedule maintenance downtime so that it becomes a regular part of the manufacturing day. TPM is currently acknowledged as a maintenance program that incorporates the introduction of operations to execute maintenance on equipment, a freshly established term. The goal of TPM, according to Nakajima, who is frequently credited as the inventor of TPM, is to increase equipment efficacy and production. It does this by making a commitment to achieving and maintaining the best possible equipment conditions in order to avoid unforeseen equipment failures, speed losses, and process quality flaws.
By including the staff at every step of TPM implementation, it should also be possible to boost morale and job satisfaction among the workforce.
In order to improve TPM, Nakajima created five pillars in 1988: equipment life cycle, training, maintenance improvement, production involvement, and equipment improvement. Kennedy (1998) claims that chances were wasted in the 1980s as a result of subpar production scheduling, leading to the creation of the second generation of TPM, which was production process-focused.
Quality and safety-related TPM challenges have recently been recognized as "essential pillars" of TPM. Kennedy asserts that as a result, in 1998, TPM now has three generations and two more pillars. Generally, the majority of the accepted definitions of TPM provided by writers like Bamber et al. (1999), Rich (1999), Cooke (2000), Blanchard (1997), Davis (1995), and Willmott (1997) expand on the fundamental five pillars described by Nakajima (1988). They claim that in order for TPM to succeed, all five basic pillars must be applied to effectively and sustainably reduce equipment losses.

## 2.7. Measurement of Total Productive Maintenance Effectiveness

Manufacturing performance can be measured in a variety of ways, but the most popular method, according to published literature, uses cost, overall equipment effectiveness, quality, delivery, and customer satisfaction as the key metrics (Hon, 2005). According to McKone, Roger, and Kristy (1999), TPM is strongly and favorably related to cheap cost, high levels of quality, and great delivery performance. Overall Equipment Effectiveness (OEE), a quantitative statistic provided by TPM, is used to assess the productivity of industrial equipment (Nakajima, 1988).

### 2.7.1. Overall Equipment Effectiveness

The standard evaluation metric for total productive maintenance that must be optimized compares actual plant performance to ideal performance potential is known as overall equipment effectiveness (Lanza et al., 2013).

For industrial companies, the analysis of the effectiveness of the production systems is an important subject. In order to develop action plans and solutions for the primary causes of production efficiency, it is possible to calculate and monitor resource productive efficiency in order to learn about their actual efficiencies. It is necessary to gather and analyze data from the productive resources because the company's corporate systems do not include the information necessary for calculating resource efficiency correctly (Passos et al., 2004).
The Overall Equipment Effectiveness is one of the TPM philosophy's most crucial instruments (OEE). Three parameters that are important to the TPM concept are multiplied to produce the OEE indicator (Fuentes, 2006; Muchiri and Pintelon, 2008). In light of the average OEE in producing companies, which has been shown to be about 60% (Ryll et al., 2010), it could be appropriate to aim for at least an index of 85% in addition to the increased productivity and economic benefits that OEE brings.

OEE is a technique for understanding the manufacturing area's performance as well as for spotting potential limitations (Hansen, 2002). OEE determines the manufacturing process's percentage effectiveness. OEE also includes the three components of availability, performance efficiency, and quality. OEE= availability*performance*quality

Availability: It is the difference between the amount of time that equipment has been operational and the time that it has been programmed to operate.
Availability = Operating time/planned production time
Performance: It refers to how closely the machinery operates to the ideal production cycle. The shortest cycle time that a process can reasonably be expected to accomplish under ideal conditions is known as the ideal cycle time (Ryll et al., 2010). It can alternatively be expressed as Nameplate Capacity, Design Cycle Time, or Theoretical Cycle Time. Performance is capped at 100% or higher to guarantee that the impact on OEE will be minimal if an error is made when defining the Ideal Cycle Time or Ideal Run Rate.
Performance = ideal cycle time/operating time
Quality: It is the ratio of the total number of high-quality pieces created to the entire amount of Product.
Quality = total product-rejected product/total product

**World Class OEE in Construction Sector**

Understanding the operating principles of construction equipment, how to handle it, and where it is most effective to use it is crucial in the construction sector. In the current construction industry, construction equipment has assumed a significant role, particularly for engineers. Construction of roads (both paved and unpaved), dams, runways, power plants, irrigation schemes, water and wastewater works, etc., includes numerous earth moving operations that require a lot of equipment. Construction equipment is being used more and more frequently to complete tasks. In modern civil engineering projects, plant and equipment account for a significant portion of the construction costs. The cost component often depends on the type of project work involved and how much equipment is used. The equipment expenditures in a construction project can range from 5% to 10% of the direct costs. While in a proposal for building a roadway, plant and equipment costs could account for up to 40% of the project's direct costs. Contractors and practicing experienced Engineers in the field must therefore understand the principles of the equipment. Total Productive Maintenance (TPM) is essentially a maintenance program and includes a newly defined concept for managing facilities and equipment, uses OEE as key criteria. (Pratik D.et al, 2017).

Fully Productive Time to Planned Production Time is measured by OEE (Ryll et al., 2010). OEE, however, is actually calculated as the sum of its three underlying components: availability, performance, and quality. OEE= Availability*performance*quality
The generally accepted World Class target for each factor is as shown in the table below:

Table: 2. 2 OEE Factor World Class

| | |
|---|---|
| Availability | 90.0% |
| Performance | 95.0% |
| Quality | 99.9% |
| OEE | 85.0% |

Of course, each production facility is unique. A facility, for instance, may not be content with a first-run quality rate of 99.9% if it has an active Six Sigma quality program. The average OEE percentage in manufacturing plants, according to studies conducted around the world, is 60%. The table above shows that an OEE that is deemed to be in the world class is 85% or higher.

OEE should initially be used on bottlenecks or other important equipment. When properly implemented as a result of tracking and enhancing OEE, these areas will significantly enhance the manufacturing line's overall performance (Hansen, 2002). OEE rates are as follows when OEE numbers have been established for the process's assets and all staff is aware of their importance and meaning (Blanchard, 1997; Robert C. Hansen, 2002).

- < 65%, unacceptable, bad management of resources.
- 65-75%, only if the trend is improving, fairly acceptable.
- 75-85% is fine, but adoption is likely to improve, thus it should be sought after to do so.
- 85–90% world-class standard.
- Industries that use continuous on-stream processes ought to have OEE ratings of 95% or higher.

## 2.8. Six big Losses

One of the main objectives of TPM and OEE programs, according to Venkatesh in 2007, is to reduce and/or eliminate what are known as the Six Big Losses, which are the most frequent reasons for efficiency loss in manufacturing.

The six big losses are the main reasons for production shortfalls, making them essential to overall equipment effectiveness (OEE). The Wastes are connected to them. Employees can identify the six major losses by being aware of them and can then eliminate or significantly reduce them (Chadli, 2014).

**Breakdown's losses**

They typically happen when an unanticipated event halts operations, such as a malfunction in equipment or the need for emergency maintenance (Induswe (2013).

**Setup and Adjustments**

This is also considered a downtime loss. Here, productivity decreases or ceases altogether as adjustments are made in anticipation of a shift in production. Examples include changing tools, dies, or equipment and waiting for supplies, components, or people (Induswe, (2013).

**Small Stops**

Short-term speed loss is what is happening here. Blockages, jams, cleaning, and inspection are a few examples (Induswe (2013).

**Slow Running**

This is categorized as a loss of speed. Equipment not operating as quickly as it should be is the problem here. Poor setup, wear and tear, and poor maintenance are among the causes (Induswe, (2013).

**Start-up Defects**

This qualifies as a loss of quality. Typically, there is waste at the beginning of a production cycle because certain parts may be defective (Induswe, (2013).

**Production Rejects**

This are unreliable products or defective manufactured goods, production of articles, parts and other equipment that doesn't correspond in quality to standards, technical specifications and other technical norms.

Table: 2. 3 Six big Losses Summary

| Six Big Loss Category | OEE Loss Category | Event Example | Comment |
|---|---|---|---|
| Breakdowns | Downtime Loss | ▪ Failures of equipment<br>▪ unanticipated maintenance<br>▪ general breakdowns, and tooling | Where the line is drawn between a Breakdown (Down Time Loss) and a Little Halt is negotiable (Speed Loss) |
| Setup and Adjustments | | ▪ substantial adjustments<br>▪ material shortages<br>▪ operator shortages<br>▪ setup/changeover delays<br>▪ Warm-up times and major modifications. | Programs to reduce setup time are frequently used to alleviate this loss. |
| Small Stops | Speed Loss | ▪ obstructing the passage of goods<br>▪ clogs in components<br>▪ A sensor was blocked.<br>▪ Delivery was blocked. | Usually, stops that are brief and without the need for maintenance staff are included. |
| Reduced Speed | | ▪ harsh operating<br>▪ under nameplate<br>▪ capacity<br>▪ under design capacity<br>▪ equipment wear<br>▪ Ineffective operator and more. | Anything prevents the process from operating at its theoretical top speed (Ideal Run Rate or Name plate Capacity). |
| Startup Rejects | Quality Loss | ▪ Scraping<br>▪ Reworking<br>▪ in-process harm pending expiration<br>▪ improper assembly | Rejections that occur at startup, warm-up, or other early production. Maybe brought on by a poor setup, a long warm-up, etc. |
| Production Rejects | | ▪ Scraping<br>▪ reworking<br>▪ in-process harm pending expiration<br>▪ improper assembly | During steady-state manufacturing, rejects. |

## 2.9. Pillars of TPM

The introduction of TPM program is based on the methodical application of a set of 8 TPM pillars, according to a proposal made by the Japan Institute of Plant Maintenance, in order to maximize plant and equipment efficiency by establishing the ideal interaction between people and machinery (JIPM). The image below depicts the basic structure of TPM.

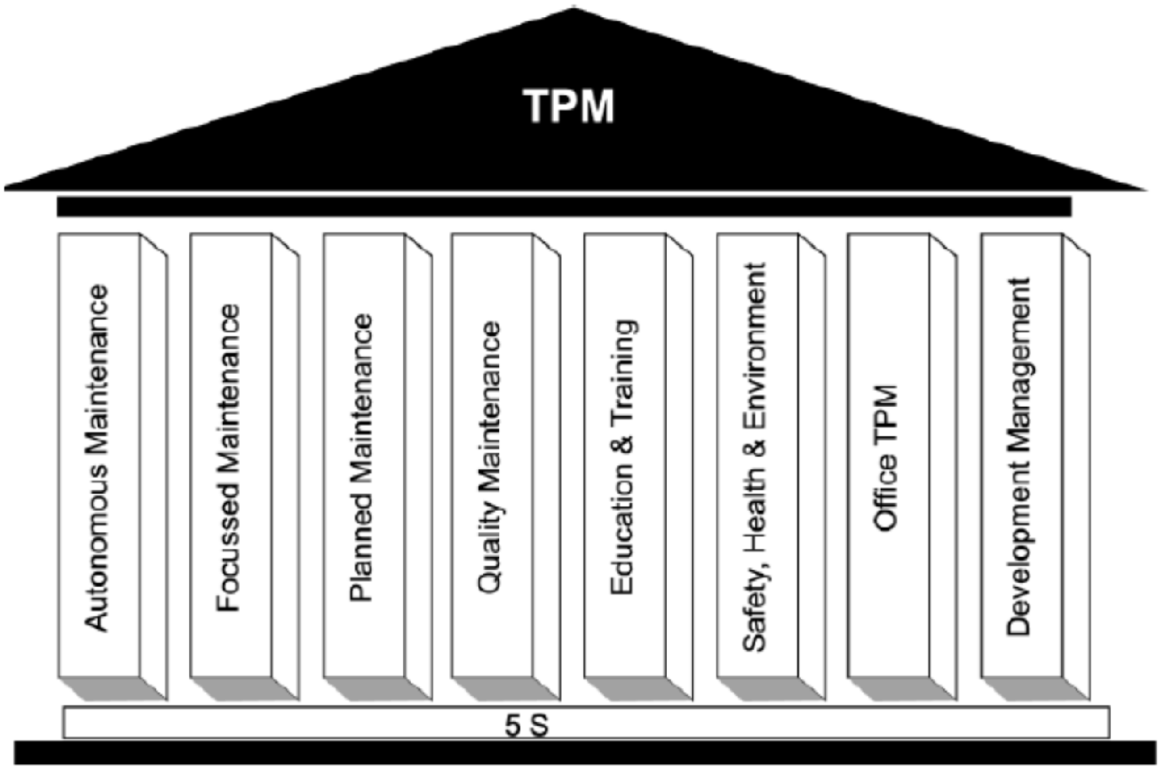



Figure: 2. 2 eight pillars approach for TPM implementation (Source: by Japan Institute of Plant Maintenance 1971)

### 2.9.1. Autonomous Maintenance

Autonomous maintenance is defined by Robinson and Ginder (1995) as the process when equipment operators accept and share responsibility with maintenance staff for the increased performance and health of their equipment. The establishment of "professional equipment operators" for the aim of "preserving their own equipment" is the fundamental tenet of autonomous maintenance (Shirose, 1996) the core of TPM operations is autonomous maintenance (Komatsu, 1999). The goal of autonomous maintenance is to advance the skill sets of equipment operators and create a well-organized shop floor where the operator can quickly identify deviations from ideal circumstances (Tajiri and Gotoh, 1992). Even if the other TPM pillars are maintained, if autonomous maintenance operations are not done successfully, the desired effects will not be seen (Komatsu, 1999).

The five-step process and the seven-step strategy are suggested for correctly implementing autonomous maintenance (Nakajima, 1988). After performing operator training and rehabilitation to enable them to carry out some basic maintenance duties for the equipment, keep it in excellent operating condition, and avoid any equipment deterioration, autonomous maintenance is implemented. Additionally, conducting daily routine maintenance tasks and learning some basic repairs are part of the course. As a result, workers ought to be able identify defects and fix them without having to halt work and wait for experts for an extended amount of time. As a result, autonomous maintenance is a self-maintenance effective strategy that is dependent on the level of training and skills of personnel who operate the equipment. It also requires a certain level of collaboration between various sections and departments of operation and maintenance.

Therefore, it is the TPM pillar that is the most fundamental. Equipment operators must become competent managers of their production processes in order to perform autonomous maintenance. They must be able to recognize signals of productivity loss, spot irregularities, and take appropriate action in response to their findings.

### 2.9.2. Focused Maintenance

Focused maintenance refers to any operations that increase the overall efficiency of facilities, procedures, and machinery by reducing losses and enhancing output (Suzuki, 1994). Focused development aims to make equipment work exceptionally well every day. The more efficiently the machines work, the more productive the shop floor is, and the more prosperous the company is (Leflar, 2001). Zero losses are the core tenet of targeted improvement. According to (Nakajima, 1988), eliminating all failures, faults, and other undesirable phenomena which are often regarded as the wastes and losses caused in equipment operation is necessary to maximize equipment effectiveness.

### 2.9.3. Planned Maintenance

Planned maintenance's primary goal is to create and maintain ideal conditions for equipment and processes (Suzuki 1994). By increasing machine availability, the establishment of a planned maintenance system entails maximizing productivity and enhancing the skill of maintenance specialists. By effectively implementing these tasks, maintenance input can be reduced and a fluid, integrated system can be built. These tasks include routine preventive maintenance to stop failures, corrective maintenance, daily maintenance prevention, breakdown maintenance to get machines back up and running as soon as possible after failure, and guidance and assistance in autonomous maintenance (Japan Institute of Plant Maintenance, 1996). The achievement of zero failures is given priority in planned maintenance activities (Shirose, 1996).

To have defect-free products and high plant availability, it entails maintaining the equipment (JIPM, 2010). It also refers to carrying out the maintenance job by organizing, controlling, and planning the data pertaining to maintenance activities, such as procedures, resources, labor, and necessary timing. The goal of scheduled maintenance is to guarantee optimal equipment performance at the lowest possible maintenance costs, allowing equipment to operate at its best all the time.

### 2.9.4. Quality Maintenance

Establishing "zero defects" conditions, maintaining conditions within predetermined standards, inspecting and monitoring conditions to eliminate variation, and taking preventive measures prior to defects or equipment/process failure are all examples of quality maintenance. Quality maintenance also refers to the control of such conditions to reduce defects to zero. The primary idea of quality maintenance is that it emphasizes proactive rather than reactive actions that are conducted before something occurs (Japan Institute of Plant Maintenance, 1996). One of the main goals of TPM is to make sure that processes and equipment are so reliable that they always operate as intended (Schonberger, 1986). Reduced fast equipment deterioration, the removal of process issues, and the development of skilled and competent users are prerequisites for successful quality maintenance implementation (Shirose 1996).

### 2.9.5. Education and Training

The pillar of training and education makes sure that workers are educated in the knowledge and abilities deemed crucial to their personal growth as well as the effective application of TPM in accordance with the aims and objectives of the company (Marofi, 2014). For TPM to be implemented successfully, all employees across the board must perform better and have better abilities. The goal of the training and education pillar is to have multi-skilled, reenergized personnel that are eager to report to work, perform all necessary activities efficiently, and do so on their own. The goal of providing operators with education is to improve their skills in order to produce a factory full of experts. The goal of employee training is to help them develop their skills in the following four phases: Phases 1 and 2 are ignorance, Phase 3 is competence but not teaching, and Phase 4 is competence but also teaching (Venkatesh, 2007).

### 2.9.6. Safety, Health and Environment

One of the TPM pillars, Safety, Health, and the Environment (SHE), focuses on the attainment of zero accidents. Only with a tight focus on safety, health, and environmental issues can TPM programs be useful. The foundation of TPM is based on preventing human mistake, maintaining the dependability of equipment, and preventing accidents and pollution (Suzuki, 1994). Identifying and removing safety, health, and environmental issues is the main goal of the TPM safety, health, and environmental pillar implementation. Beyond just preventing accidents, environmental safety also refers to lowering energy usage, getting rid of toxic waste and using fewer raw materials (Pomorski, 2004). It is also referred to as (SHE).

To achieve an accident-free workplace, it requires focusing on the safety of the workplace and its surroundings. The main pillars of TPM, according to Nakajima (1988), "ensure equipment reliability, prevent human error, and eliminate accidents and pollution." The actions and resources utilized to significantly increase the efficiency of the manufacturing process are also in place to make comparable improvements in the areas of safety, health, and the environment, according to this pillar of total productive maintenance. TPM is committed to protecting workplace safety, human health, and the environment by eliminating hazards that could lead to accidents, injuries, or occupational diseases (Narender and Gupta, 2012).

#### 2.9.7. Office TPM

Office TPM is used to promote productivity, boost administrative and technical function efficiency, and find and get rid of losses. Analyzing processes and procedures with the intention of boosting office automation is part of this (Patra, Tripathy and Choudhary, 2005). By minimizing waste and loss and documenting administrative methods, these departments' productivity can be raised. They can also increase the efficiency of the production system by enhancing all coordinated activities that aid in production (Suzuki, 1994).

#### 2.9.8. Development Management

Development Management, also known as maintenance prevention, is the term for design activities carried out during the planning and construction of new equipment that give the equipment high degrees of reliability, maintainability, economy, operability, safety, and flexibility, while taking maintenance information and new technologies into account, and thereby reduce maintenance costs and deterioration losses. Suzuki 1994 defines early management as the process of identifying potential problems before they become problems (Shirose, 1996). Keeping equipment's Life Cycle Cost (LCC) as low as possible is the traditional goal of early management. The idea of early management design is broadened in TPM to encompass design that seeks to achieve not only no breakdowns (reliability) and simple maintenance (maintainability), but also prevention of all potential losses that may obstruct the effectiveness of the production system and pursuit of ultimate system improvement. By identifying flaws in current equipment and processes and relaying this information to the designers, the early management design approach increases equipment and process reliability (Suzuki, 1994).

### 2.10. Maintenance in Construction Industry

The effective utilization of construction equipment is crucial to the commercial construction sector. In order to increase a contractor's ability to complete their work more successfully and efficiently, equipment is therefore one of the most crucial factors (Day, D. A. and Benjamin, N.B.H, 1991). By increasing the efficiency of employing equipment, a sizable quantity of work can be completed in a shorter period of time and, more importantly, within the project deadline. Project delays on this construction project were attributed to a number of factors, including insufficient organizational skills, a lack of building materials, and worker inefficiencies. (Hinze, J. and Ashton, W.B 1979). Depending on how much of a project is mechanized, the cost of the equipment ranges from 10% to 30% of the total project cost (Shama S.C., 2002). The cost of equipment increases by 30% in fully automated modern projects. For the project to be completed successfully, proper planning, selection, procurement, installation, operation, maintenance, and equipment replacement policy are crucial. Construction engineers now need to be extensively knowledgeable about the construction applications and maintenance of the wide variety of modern equipment due to the increasing use of machinery. The technique of performing the work, the amount of time required to finish the operation, and the cost of construction all influence the choice of construction equipment (Day, D. A, & Benjamin, N.B.H., 1924). Therefore, effective equipment planning and administration are essential for a company's performance, particularly in the field of road project building where profit margins are extremely low. Jose (2001) defined productivity as the proportion of valuable work produced to the time required to do that work.

In this context, productivity refers to the amount of earth generated per operator hour and the quantity of labor cycles completed every operator minute. Actual productivity must be compared to a desired productivity in order to assess the level of performance (estimated). The ratio of estimated productivity to present productivity is known as the performance ability ratio (PAR) (Alfeld, 1988). When the PAR number is close to 1, it means that the present productivity is generally good, and when it is significantly more than 1, it means that the productivity is poor.

Many studies indicate that the construction sector needs to develop in all developing nations. Many authors claim that governments are in charge of the growth of the construction industry, but (Anosike, 2011) counters that attempts to advance the sector can come from construction firms as well as practitioners. He proposed two areas for development. The first is the requirement for ongoing assessment of construction regulations and standards, which should be written as technical aids rather than onerous regulations and in a language appropriate to the educational background of the majority of users.

The other is the requirement for construction businesses to raise their corporate goals for innovation, productivity, efficiency, and quality of work while setting up the right organizational structures to do so. Ethiopia is one of the developing nations with the quickest development rate in the world, so the building sector must be improved.

Due to the country's demand for infrastructure and other commercial sectors, the building industry in Ethiopia is expanding at a rapid rate. According to data from 2019, it provides roughly 24.82% of the nation's GDP. Despite Ethiopia's construction sector experiencing rapid expansion, the majority of large-scale projects are carried out by foreign contractors due to a shortage of qualified workers and amateurish craftsmanship.

#### 2.10.1. Poor Training of Equipment Operators

The final shooter who determines the productivity of the equipment is the equipment operator. Equipment abuse brought on by carelessness on the part of the operator and inadequate training and expertise on the part of the equipment supervisor may increase the frequency and expense of downtime (Pathmanathan, 1980). One of the most crucial aspects is an operator's expertise, which impacts performance and the direct cost of DT through task efficiency (Arditi et al., 1997; Elazouni & Basha, 1996; Edwards et al., 2000).

#### 2.10.2. Poor Equipment Maintenance Practices

When a piece of equipment malfunctions, production ceases completely and the owner begins to lose money instead of making it. Preventive maintenance, routine maintenance, and major repairs make up the three main parts of most construction equipment maintenance programs. The major repair program is minimized if the first two programs are both aggressively applied and well managed. More importantly, the first two programs happen as scheduled under the control of the owners, whereas major repairs happen haphazardly and typically when they seem to cause the project the most stress. Poor equipment maintenance procedures lead to catastrophic equipment breakdowns and more downtime for the equipment, which lowers its productivity and raises project costs. Consequently, in order to grasp efficient management of construction equipment, one must also comprehend efficient equipment maintenance. (Gransberg and others, 2006) The productivity of a machine depends on a variety of things. The project manager frequently has no control over factors like the weather, operator effectiveness, and operating site circumstances, all of which have an impact. The availability of the machines is the only component that can be completely controlled.

Regular scheduled maintenance is crucial to the modern construction industry's high productivity. Planning in advance is necessary to guarantee that corporate personnel always have the necessary skills, resources, and spare parts on hand to properly maintain equipment when the time for regular maintenance arrives (Graisia, 2014).

The major maintenance strategy is to take the essential actions to maintain the machinery working as efficiently as possible. Machine elements like motor and bearing lubrication, motor and belt replacement, fan blade cleaning, fan wheel balancing, compressed air system maintenance, sealing material maintenance, belt conveyer maintenance, and machine devise cleaning are all included in the maintenance of machines used in the construction industry (Shafeek 2012).

According to (Graisia, 2014), TPM was introduced to the construction industry in order to maximize machine productivity, machine OEE, working conditions, cost savings, and product profit. According to Venkatesh (2007), the introduction of TPM in any industry aids in achieving the following goals:

- Avoid wastage in a quickly changing economic environment.
- Producing goods without reducing product quality.
- Reduce cost
- Produce a low batch quantity at the earliest possible time and Products sent to the customers must be with no defect.

## 2.11. Literature Summary and Gap Identification

TPM is a continuous process and a long-term strategy, and it motivates workers to work hard and take corrective action. Global competitiveness and the need to boost the efficiency of manufacturers and production lines in every industry sector have led to the implementation of TPM as a technique to raise productivity. Any organization's application of TPM technology and work culture change, along with the involvement of employees and management, is crucial to achieving the process' goals (Blanchard, 2019).

TPM installation is a crucial business issue because it is a fundamental component and function of every firm. The major goals of TPM in industrial organizations are to improve communication between the production and maintenance departments and prevent pointless confrontations. When discussing TPM implementation in the aforementioned literatures, the authors makes it obvious how important it is for the organization to use TPM pillars. The researchers concentrated on methods to boost TPM performance effectiveness and efficiency. It also outlines the difficulties encountered when implementing TPM in different organizations. TPM is applied, solving the six big losses. It has been noticed that TPM tactics have significantly altered numerous global industrial sectors. Also, they compute numerous losses that have a direct impact on the companies' production.

In general, the evaluation can reduce the length of time needed to implement TPM by using it as a strategy for a small subset of essential equipment and introducing new components gradually. In essence, it is clearly asserted that a crucial requirement for the quick and successful implementation of TPM is the managers' and employees' willingness to accept the change for increased productivity. If they do, less than two years passed since the implementation period began.

To sum up, studies discovered that TPM installation improves with time. But, better results achieved by starting with the primary production machines, progressively developing specialized cross-functional teams from corporate departments, and giving adequate training to uphold the concept (Moore, R. and Rath, R. (, 2018). The primary goal of TPM is to achieve zero breakdowns, zero failures, and zero accidents, according to numerous researchers. The majority of them noted how implementing the TPM five pillars changed things. Also, TPM emphasizes that the production department and the maintenance department should collaborate as a single unit to prevent conflicts between them.

The pillars of TPM are linked to the levels of self-sustainability, as evidenced by a large portion of the literature evaluation, making it a crucial component of the system. As a result, this is the system's core component. Management must take operator training, upcoming planned maintenance, and focus improvement into account while implementing an independent maintenance program. The TPM process begins with an independent maintenance program. Most people concur that all devices should have the bare minimum of equipment and operator training.

In the commercial constructing industry, efficient use of construction equipment is essential. Equipment is therefore one of the most important components in enabling a contractor to carry out their business more successfully and efficiently. By improving the effectiveness of using equipment, a significant amount of work can be finished in a shorter amount of time and, more crucially, within the project deadline.

There were several reasons why this construction project was delayed, including poor organizational abilities, a lack of building supplies, and worker inefficiency. The OEE intended to increase performance and quality rates, reduce breakdowns, and increase overall machine efficiency. When increasing the Overall Equipment Effectiveness (OEE) of a management system, the machine's availability rate, performance rate, and product quality rate are taken into account as measurements. The project's goal is to increase a construction company's overall equipment effectiveness (OEE). Although TPM has been widely investigated in the textile, cement, soft drink, and other industries in Ethiopia, it has also been studied in other industries. They investigated, displayed the issues, and mentioned their suggestions.

Yet, because the construction industry in Ethiopia is rapidly growing and TPM is relatively limited in this country, this study looks at the extensive and profound knowledge gaps that exist in this industry, Concrete batching plants and construction equipment in particular at Dugda Construction. Therefore, this research will fill that gaps and add value to the scientific environment in TPM implementation in construction sector.

# CHAPTER THREE
# RESEARCH METHODOLOGY

## 3.1. Introduction

This chapter includes comprehensive explanations of the methods the researcher must follow. This section mostly discusses the strategy/design adopted by the researcher to address the study issues and justifies the strategy's selection. The primary research steps include the research design and strategies, methodology approach, data gathering method, data collection tool, and data processing and analysis method.

## 3.2. Methodology

The methodology that was employed to carry out the research mainly identifies the existing production in the company with the help of pragmatic study and focus group discussion. The average values of overall equipment efficiency and total productivity was calculated and compared to world class standards. Additionally, important suggestions were given so as to enhance the efficiency of the existing system equipment.

## 3.3. Research design

In conducting the research design which was used for the study is case study research since it was focus on a particular case company specifically Dugda construction plc. Besides, by using empirical data on the selected production and construction machines and recognizing the effect on the improvement of TPM implementation. As a result, the nature of the research was an empirical research design.

The study was conducted at Dugda construction concrete batching plant located at Addis Ababa Nefas Selk sub city project site. The company is selected for this study case since the researcher had close information in the problem area and wants to solve this issue by conducting the research. The concrete batching plant has approximately 80 workers, which include operators, technicians, managers, supervisors, and engineers.

The research design used for this study was a case study approach. The research design was chosen because it enables in-depth understanding of the topic of enhancing overall equipment effectiveness through the use of Total Productive Maintenance. A case study is a research method that enables a thorough examination of a current, real-world event in its original setting, according to Yin (2012).

The case study method has been widely employed in research on organizations and has produced a vast amount of high-quality data that has greatly advanced our understanding of organizational functioning in practice.

Case studies offer a crucial method for evaluating the TPM philosophy's efficacy in various sectors of application, particularly in the manufacturing industries (Aspinwall and Elgharib, 2013). This study employs both quantitative and qualitative research techniques.

## 3.4. Method of Data Collection

### 3.4.1. Sources of data

Both Primary and secondary data were the main data sources for this study:

Primary data: Trochim, (2003) makes the case that alternative forms are intended to be equal to the kinds of inquiries that determine the conclusion with regard to primary data. Similar to this, Kothari, (2006) explains that primary data is gathered using either questionnaires or interviews. In light of this, the core data for this study were directly gathered from the sample respondents using the chosen instruments covered in the following subsections.

Secondary data were also gathered in addition to the primary data from various kinds of publications such as journals, academic papers, reports, etc. In addition to this, academic written materials from reliable web sources were used to round out the data.

The researcher compared the company's Productivity using the monthly production records.

A questionnaire and structured interview questions were used by the researcher to collect data. Two sections of structured questions were used in the questionnaire. The demographic background of the respondents made up Part I. In order to address the research questions, Part II covers respondents' perceptions of the effectiveness of the companies' implementation of specific TPM pillars as well as its effects.

The researcher designed the structured interview questions in order to gather data through interviews. Most of the structured questions were of the closed-end variety, and respondents were instructed to tick the box next to the correct response.

**Interview:** It is a conversational data collection method. The primary method of acquiring data is through interviews, which are a type of verbal questioning. It is one of the most widely used methods in survey research, according to Robson (1993). Unstructured interviews were used in the research to gather more in-depth data on the subject. Interviews with the two maintenance supervisors and the three production supervisors were conducted to get first-hand knowledge on how the chosen TPM pillars impact manufacturing performance at the plant.

**Questionnaire:** (Sarantakos, 1993; Robson, A., 1993) describes a questionnaire as a written question in the form of text and states that it can be self-administered by the researcher or distributed via mail. The respondent gives information. The researcher used closed-ended questions that were designed for operators of machines, technicians, production supervisors, and maintenance supervisors.

**Observation:** The researcher observed the overall setting of the company's production and production-related departments, the organization maintenance store, the layout of the workshop, batching plant primary production and machinery, and the company's production and maintenance records both before and after applying selected pillars. Other things had been observed like how the daily equipment inspection and lubrication activities conducted during the normal operation times. Direct observation used in collecting data without relying on other collection mechanisms. All relevant documents, maintenance manuals, monthly equipment maintenance record history was referred for the research study. In order to determine the area where the TPM program might be implemented most successfully, the background necessary for the development and implementation of TPM was researched.

**Document and recording analysis:** The Company's yearly reports and records pertaining to production and maintenance improvement from previous years were reviewed. In order to develop total productive maintenance (TPM) for a one-year period (April 1, 2022 through March 31, 2023), equipment history data collection, which includes actual production, downtime, six big losses, and product quality rate, was carried out. This was followed by the establishment of an attainable and realistic TPM target.

### 3.4.2. Population and Sampling Procedure

The term "population" refers to the group that the researcher is interested to learn more about and from which a sample was taken. Frequently, this is explained in terms of location, demography, season, etc. Even though the case company has over 80 workers overall, only the top management and shop floor workers were included in the target population for this study, which is mentioned in the table below. The others are support workers.

Table: 3. 1Sample population

| No. | Staffs | Qty. |
|---|---|---|
| 1 | Production Supervisors | 3 |
| 2 | Maintenance Supervisors | 3 |
| 3 | Machine Operators | 38 |
| 4 | Mechanical and electrical technicians | 19 |
| 5 | Quality controllers | 2 |
| | **Total** | **65** |

L. R. Gay (2008) states that "10% of large populations and 20% of small populations as minimums can be taken as sample size". However, in order to obtain more reliable information from various respondents, the researcher only included 30% of the target population in the study. Due to the limited population, three maintenance supervisors from the mechanical and electrical department were chosen by target sampling that represents 100% of the population. Eight technicians, one quality controller, and fourteen machine operators were also used as sample respondents for questioner.

Table: 3. 2 Total Population and Sample Size

| No. | Respondent | Population | Sample Size ≥30% | Sampling Techniques |
|---|---|---|---|---|
| 1 | Production Supervisors | 3 | 3 | Target Sampling |
| 2 | Maintenance Supervisors | 3 | 3 | ” |
| 3 | Machine Operators | 38 | 14 | ” |
| 4 | Mechanical and electrical technicians | 19 | 8 | ” |
| 5 | Quality controllers | 2 | 1 | ” |
| | **Total** | **65** | **31** | |

## 3.5. Methods of Data Analysis

Descriptive statistics such as frequencies, percentage, graphs, Pareto charts were used for the collected data analysis. Both qualitative and quantitative data analysis approaches were used to assess the maintenance systems and to calculate the overall equipment efficiency. In descriptive methods research, the type of methodology selected for the procedures has an impact on data analysis. The database was kept up to date using the SPSS.24.0 software, which was used as well to analyze the descriptive data. The data gathered from various sources have been categorized, coded, and summarized as described in the sampling approach section to prepare for analysis. While the closed-ended questions have been coded and analyzed using both descriptive and inferential statistics using correlation, percentages, frequencies, the T-test, and measures of central tendency and desperation, the qualitative or open-ended questions have been summarized and presented as-is. Depending on the respondents' response, the data outputs were presented accordingly.

The level of significance of the respondents' responses' variance was thus assessed using the T-test. In addition to descriptive analysis, the pillars are prioritized using the analytical hierarchy approach, which aids in the choice of the more important pillars. The final product has been presented in written and table form. Using the results of the analysis and the interpretation of the data, conclusions and recommendations were then be made and presented in a written format.

A comparative analysis of the existing maintenance record data and the new implementation strategies were used to show the significance of the philosophy. After having made a detailed analysis of the results and findings of the research, appropriate method and time of TPM implementation was proposed. Moreover, the key success factors, results, and challenges that the case company faced were compared, discussed and interpreted in relation to the relevant literature.

Root cause and down time analysis for the major problems were done by using statistical quality control tools such as fish bone and Pareto diagram.

The study was involved tabulation of all factors principal to the calculation of the overall equipment efficiency and productivity of the main equipment and its direct influence in determining the efficiency of the existing equipment and also the collected data was analyzed graphically using the appropriate method of data analysis. One maintenance division head, one production head, and two mechanical engineers were in charge of each process of TPM implementation. The researcher was given a brief introduction of the study to the management of the batching plant upon initial contact. The researcher and management then built a cross functional team of two experienced batching plant operators, one civil engineer and quality engineer from the production unit, and a maintenance department consisting of one maintenance division head, two mechanical engineers, two senior mechanics, and one electromechanical expert.

The discussion was done to raise awareness and explain the TPM, and those in the profession expressed their views on the problems they said were related to the current situation of concrete batching plants. In general, the researcher, based on the discussions with the maintenance department and the production department, found that the reduction in production and the constant breakdown of the batching plant had an impact on customers, and that conflicts between the maintenance department and the production department were increasing.

Due to the lack of regular inspection and cleaning by the maintenance department, the breakdowns in various parts of the batching plant are increasing. The production department is only concerned with the production of the concrete and not the batching plant; the maintenance department and the production department focus on conflict and blame instead of solving the problem together at the batching plant. The team was participated throughout the implementation of TPM. In this team, teammates were familiar with the maintenance and operation of the batching plant or processes chosen. Finally, the operators were assisted the researcher in collecting the data for each process.

Table: 3. 3 Analysis Methods

| **No.** | **Data items** | **Method of Analysis** | |
|---|---|---|---|
| | | Analysis Tools | description |
| 1. | closed-ended survey for supervisors, operators, and technicians | SPSS 24.0 | It was analyzed correlation, percentage, mean, standard deviation, and t-test quantitatively. |
| 2. | Checklist for the documentation related to manufacturing production and downtime during breakdowns | Pareto Charts, root cause analysis, and tables | Here, the researcher observed the company workshop, late-running production equipment, and productivity-related records. Analysis was done using a quantitative approach (tables, Pareto charts, etc.). |
| 3. | For the production and maintenance supervisors, open-ended interviews | SPSS 24.0 | Based on their frequency, these qualitative data was evaluated. |

## 3.6. Reliability and Validity Test of the Survey

The results of the questionnaire, which were obtained from the responses of 31 company employees, are presented in this section. Employees selected at random from the category of their status. Production supervisor, Maintenance supervisors, Maintenance Engineers, Quality controllers, Technicians, and Machine Operators are among the respondents from the organization who are best suited to respond to the survey questions. Despite the initially unimpressive response rate, attempts were made to boost response. The ultimate response rate was 97% based on legitimate responses as a consequence. The responses were analyzed using the statistical SPSS Version 24.0, and the results are reported in the Appendix.

### 3.6.1. Reliability test

The degree to which the measurements (eight constructs) imply a common latent (unobserved) construct was determined using reliability analysis, also known as internal consistency. It has to do with how consistently an experiment, test, or other measuring process provides the same results over time (Cramer, 1998). For this purpose, Cronbach's Alpha (α) is frequently utilized, where values of alpha range from 0 to 1.0, with higher values denoting more dependability.

There are different reports about the acceptable values of alpha, ranging from 0.70 to 0.95. A low value of alpha could be due to a low number of questions, poor interrelatedness between items or heterogeneous constructs. Therefore, reliability was tested on improving the overall effectiveness of Construction Equipment by Using Total Productive Maintenance.

The total number of complete feedbacks received was 31 sample populations. In order to confirm the reliability of the data, Cronbach's Alpha calculated for sixty-four variables. The overall variables have a Cronbach's alpha coefficient of 0.870 for sixty-four which is more than 0.7 as the result, the result good consistence and reliable.

Table: 3. 4 internal consistency test result

| Factors | Pillars of TPM and Manufacturing performance dimensions | No. of Items | Cronbach's α value |
|---|---|---|---|
| Pillar1 | Autonomous Maintenance | 7 | 0.846 |
| Pillar 2 | Focused maintenance | 5 | 0.906 |
| Pillar 3 | Planned Maintenance | 5 | 0.823 |
| Pillar 4 | Quality Maintenance | 6 | 0.680 |
| Pillar 5 | Education & Training | 5 | 0.879 |
| Pillar 6 | Safety, health and environment | 4 | 0.829 |
| Pillar 7 | Office TPM | 4 | 0.707 |
| Pillar 8 | Development management | 4 | 0.705 |
| MP1 | Cost | 6 | 0.906 |
| MP 2 | Quality | 5 | 0.602 |
| MP 3 | Availability | 7 | 0.955 |
| MP 4 | Delivery | 5 | 0.983 |

Table: 3. 5 Overall Cronbach's Alpha Value *(Peters, 2014)*

| **Reliability Statistics** | |
|---|---|
| Cronbach's Alpha | N of Items |
| 0.870 | 64 |

### 3.6.2. Validity Test

The ability of a component or set of items to accurately measure the underlying construct for which they are intended is known as construct validity. Confirmatory factor analysis was used in this study to test the validity of the components for each TPM aspect (Bagozzi, 2001). The purpose of factor analysis for structure detection is to look at the latent or underlying relationships between the variables.

The Kaiser-Meyer-Olkin, Measure of Sampling Adequacy (KMO), a statistic that shows the percentage of variance in the variables that can be caused by underlying factors and for construct validity, is the factor analysis test that is utilized. High KMO test values (around 1.0) typically suggest that the data may benefit from a factor analysis. The results of the factor analysis are probably not going to be very relevant if the value is less than 0.50. If the number is less than 0.5, Kaiser (1994) also suggests either gathering more data or excluding particular factors. As shown in Table 3.5, the KMO values for each factor in this study range from 0.601 to 0.774 and were deemed satisfactory.

Table: 3. 6 validity test with principal component analysis and KMO test

| Factors | Pillars of TPM and Manufacturing performance dimensions | Item deleted | Factor Loading | KMO Value |
|---|---|---|---|---|
| Pillar1 | Autonomous Maintenance | None | 0.552-0.906 | 0.643 |
| Pillar 2 | Focused maintenance | None | 0.680- 0.846 | 0.621 |
| Pillar 3 | Planned Maintenance | None | 0.530-0.784 | 0.742 |
| Pillar 4 | Quality Maintenance | None | 0.652-0.865 | 0.741 |
| Pillar 5 | Education & Training | None | 0.54-0.926 | 0.765 |
| Pillar 6 | Safety, health and environment | None | 0.682-0.873 | 0.682 |
| Pillar 7 | Office TPM | None | 0.714-0.910 | 0.732 |
| Pillar 8 | Development management | None | 0.683-0.773 | 0.689 |
| MP1 | Cost | None | 0.542-0.792 | 0.593 |
| MP 2 | Quality | None | 0.586-0.821 | 0.612 |
| MP 3 | Availability | None | 0.623-0.743 | 0.604 |
| MP 4 | Delivery | None | 0.562-0.842 | 0.586 |

**Correlation test**

Correlation test was undertaken to examine the relationship between the dimensions of TPM pillars such as autonomous maintenance, focused improvement, planned maintenance, quality maintenance, education and training, early equipment management, office TPM, safety, health, and the environment with manufacturing performance dimensions like cost, quality, availability and delivery variables. Thus, correlation between the dimensions of TPM pillars and each manufacturing performance dimensions was analyzed as below. Pearson correlation was used to measure strength and the direction of linear relationship between variables. The relationship was considered weak when r = ±0.1 to ±0.29, while the relationship was considered moderate when r = ±0.3 to ±0.49, and when r= ±0.5 and above, the relationship was considered strong.

Figure 3.1 indicates the methodological framework followed to conduct this research

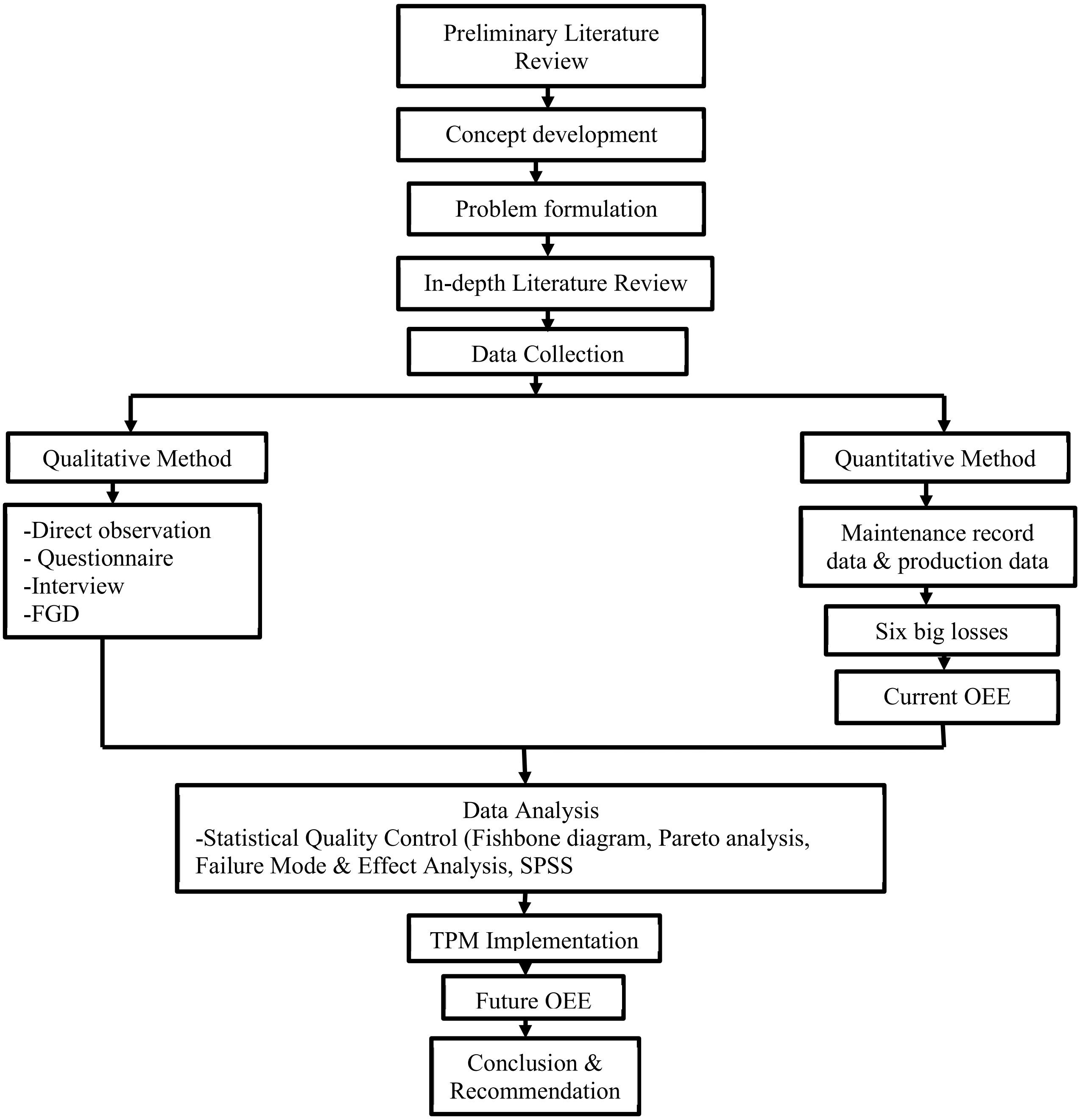



Figure: 3. 1 Methodological framework

# CHAPTER FOUR

# DATA ANALYSIS, RESULTS AND DISCUSSION

## 4.1. Introduction

An overview of the concrete production process is provided in this chapter, along with a statistical analysis of the production data and construction downtime for the Dugda construction.

### 4.2. Present Situation of the Case Company

The qualitative results and direct observation of the work area around the concrete batching plant indicate that the maintenance work in the company is mainly carried out by the maintenance department and no other departments are involved.

No inspection program, timely greasing, corrective maintenance and periodic cleaning of the batching plant are given attention to in the maintenance department. Since the maintenance department was following a run to failure maintenance, equipment operations were not stable and problems were not detected before breakdowns occur. During breakdown maintenance, it is not usual to find the cause of the failure, but to replace and repair the parts, for example (Failure mode analysis, cause and effect analysis and they don't have identify root cause of the problem).

Currently, due to the constant breakdown of the batching plant, the good working relationship between the production department and the maintenance department is causing unnecessary arguments and conflicts. This is because the head of the production department said that the batching plant was not properly repaired so we could not produce the concrete.

Also, the production department, which is prepared according to the needs of the customers, is delaying the production program and due to the difficulty in handling the back orders, the relationship between the customers and the company is leading to a conflict instead of understanding and agreeing to the problem. In this situation, when the batching plant suddenly breaks down before the production is completed, the customer demands the refund of the payment due to the production being cut. Permanent customers have started to turn their faces to the same concrete manufacturing companies due to their lack of trust in the company.

Due to the batching plant's production department not being able to work according to the plan, the plant needs to buy raw materials such as aggregate, cement, sand, chemicals, etc. at high cost and plan to make a profit by producing a lot of the raw materials that they have imported.

In addition, the operators of the batching plant do not know what to do with the plant on a regular basis and do not have enough professional knowledge and experience in preventive maintenance and the damage that can be caused by not cleaning the plant. Also, due to the lack of awareness, they do not have the knowledge to take care of the plant.

In general, due to the constant breakdown of the batching plant, the company not only loses the income it deserves, but also reduces the relationship between customers and the company, increases maintenance costs, shortens the plant's service life, and increases the possibility of the company going bankrupt.

### 4.3. Description of Batching Plant and Concrete Production

A concrete batching plant, sometimes referred to as a concrete mixing plant, is a piece of machinery used to mix huge quantities of concrete by combining aggregate, cement, water, and additive. Concrete mixers, an aggregate batcher, a weighing system, cement silos with a cement screw conveyor, a batching plant control system, and other components make up a concrete batching plant.

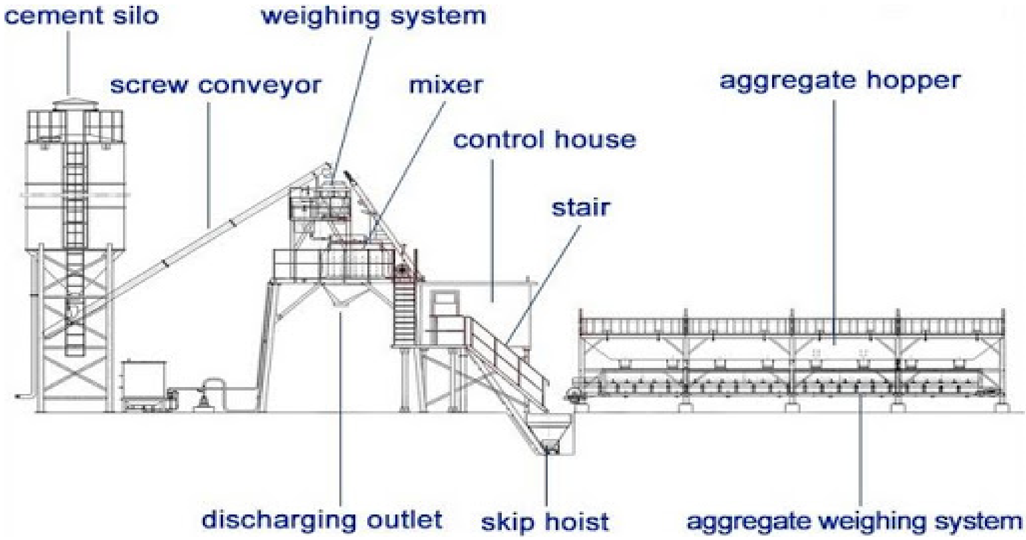



Figure: 4. 1 Concrete batching plant production process (source case company)

The processes in a concrete batching plant are: Weighing and belt conveyor or skip hoist hopper feeding of aggregate into mixer. Cement (fly ash or powder), water, and additives are all fed into the mixer at the same time. With a cement screw conveyor, cement is fed into the mixer. Following weighing, all the materials are fed into the mixer, where they are combined by the twin shaft concrete mixer. Some of the key elements of the concrete batching plant include: Aggregate feeders, Weigh conveyor for aggregates, Charging conveyor/Skip, Cement weighs scale, Water weigh scale, Additive weigh scales, A cement silo or hopper with a screw conveyor, the mixing unit, Air compressor, and Control panel.


Figure 4. 2: Pictorial view of the case company batching plant (source case company)

As it is indicated in table below, the annual equipment availability for the period April 1, 2021 up to March 31, 2022 was 64.97 % against a world class target of 90% and the OEE is 45.23 % against the world class target of 85%. Therefore, the need for the implementation of TPM is highly crucial for the company to improve its productivity**.**

Table 4. 1: Annual availability, performance, quality and OEE

| **Factors** | **Dugda Construction (%)** |
|---|---|
| Availability | 64.97 |
| Performance | 70.33 |
| Quality | 98.99 |
| OEE | 45.23 |

Source: overall equipment effectiveness of case company

Table: 4. 2 Measurement of availability before improvement

| Month | Number of working days | Working hrs./d | Planned Production Time (hr./month) | Downtime (hr./month) | Actual Production Time (hr./month) | Ideal Capacity ($m^3$/d) | Installed Capacity ($m^3$/d) | Actual Capacity ($m^3$/d) | AR |
|---|---|---|---|---|---|---|---|---|---|
| Apr 21 | 26 | 10 | 260 | 80.4 | 179.6 | 1320 | 1200 | 880 | 69.08% |
| May 21 | 28 | 10 | 280 | 86.8 | 193.2 | 1320 | 1200 | 875 | 69.00% |
| June 21 | 28 | 10 | 280 | 84 | 196 | 1320 | 1200 | 870 | 70.00% |
| July 21 | 28 | 10 | 280 | 87.5 | 192.5 | 1320 | 1200 | 887 | 68.75% |
| Aug 21 | 28 | 10 | 280 | 89 | 191 | 1320 | 1200 | 880 | 68.21% |
| Sep 21 | 26 | 10 | 260 | 103.8 | 156.2 | 1320 | 1200 | 865 | 60.08% |
| Oct 21 | 28 | 10 | 280 | 102 | 178 | 1320 | 1200 | 887 | 63.57% |
| Nov 21 | 28 | 10 | 280 | 97 | 183 | 1320 | 1200 | 855 | 65.36% |
| Dec 21 | 28 | 10 | 280 | 102.8 | 177.2 | 1320 | 1200 | 875 | 63.29% |
| Jan 22 | 26 | 10 | 260 | 103 | 157 | 1320 | 1200 | 870 | 60.38% |
| Feb 22 | 28 | 10 | 280 | 108.6 | 171.4 | 1320 | 1200 | 879 | 61.21% |
| Mar 22 | 28 | 10 | 280 | 110 | 170 | 1320 | 1200 | 855 | 60.71% |
| **Total** | 330 | 120 | 3,300.00 | 1,154.90 | 2,145.10 | 1,5840 | 1,4400 | 1,0478 | 65.00% |
| Avg. availability | | | | | | | | | 64.97% |
| Source: cases company the data was collected from April 1, 2021 up to March 31, 2022 | | | | | | | | | |

This data was collected from April 1, 2021, up to March 31, 2022, G.C. As the table shows, there are 330 working days from April 2021 to March 2022. It is also included in the plan that the concrete batching plant was working for ten hours a day. In addition, the planned production time for each month is defined, so the total planned production time for one year is 3,300 hours. Based on the downtime data collected from the maintenance department, each month is mentioned, and the recorded downtime during the year is 1,154.90 hours.

Next, with the data collected from the production department, the actual production time of the batching plant is mentioned in the table every month. In general, the data of the year, that is, from April 2021 to March 2022, concrete batching plant actual production time recorded is 2,145.10. Therefore, average concrete batching plant availability was 65%.

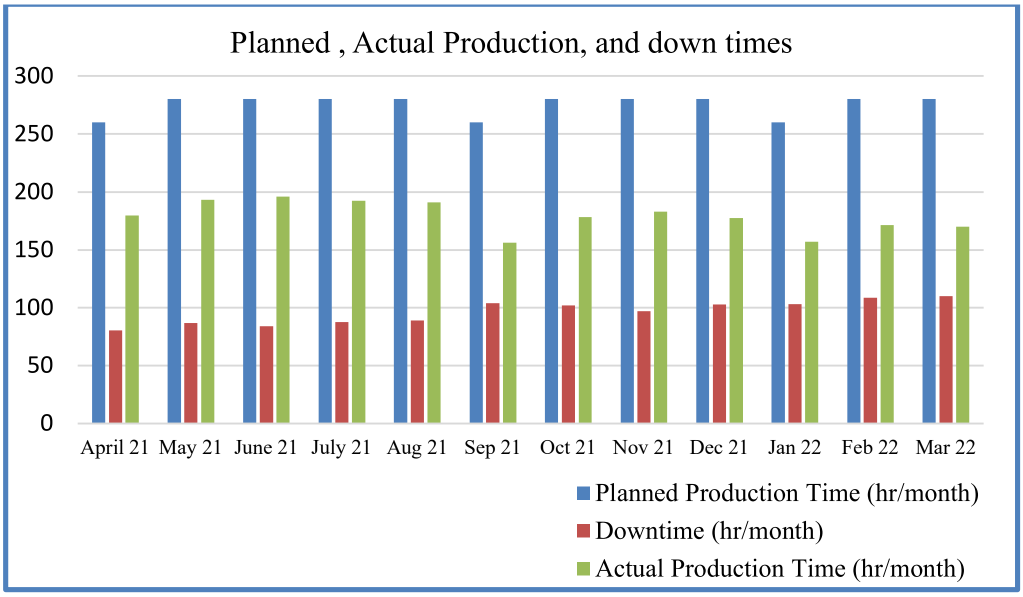



Figure 4. 3 Comparison of planned, actual production, and down times (in hours)

Figure 4.3 illustrated that the actual production of the batching plant for each month was below the planned times due to an increase in machine downtimes. To achieve the planned production time, the researcher tried to implement TPM in the case company batching plant and all supportive departments so as to address the breakdown and related issues. Before starting the implementation, the researcher decided to plan and apply TPM implementation schedule which can be applied in parallel with the company normal operation time to integrate the manpower and production schedule.

Table 4. 3: Onsite production data collection to determine OEE

| Month | Planned Production ($m^3$/month) | Ideal Cycle time | Actual Production ($m^3$/month) | Actual Production Time (hr./month) | Performance Efficiency | Reworked ($m^3$/month) | Rejected ($m^3$/month) | Total Defect ($m^3$) | Quality Product ($m^3$) | Quality Rate |
|---|---|---|---|---|---|---|---|---|---|---|
| April 21 | 21,600 | 0.008 | 15,805 | 179.6 | 70.40% | 95 | 76 | 171 | 15,634 | 98.92% |
| May 21 | 25,200 | 0.008 | 17,002 | 193.2 | 70.40% | 76 | 57 | 133 | 16,869 | 99.22% |
| June 21 | 25,200 | 0.008 | 17,052 | 196 | 69.60% | 95 | 76 | 171 | 16,881 | 99.00% |
| July 21 | 25,200 | 0.008 | 16,940 | 192.5 | 70.40% | 76 | 47.6 | 123.6 | 16,816 | 99.27% |
| Aug 21 | 25,200 | 0.008 | 16,808 | 191 | 70.40% | 95 | 57 | 152 | 16,656 | 99.10% |
| Sep 21 | 23,400 | 0.008 | 13,746 | 156.2 | 70.40% | 95 | 47.6 | 142.6 | 13,603 | 98.96% |
| Oct 21 | 25,200 | 0.008 | 15,664 | 178 | 70.40% | 76 | 76 | 152 | 15,512 | 99.03% |
| Nov 21 | 25,200 | 0.008 | 16,104 | 183 | 70.40% | 95 | 47.6 | 142.6 | 15,961 | 99.11% |
| Dec 21 | 25,200 | 0.008 | 15,594 | 177.2 | 70.40% | 114 | 57 | 171 | 15,423 | 98.90% |
| Jan 22 | 21,600 | 0.008 | 13,816 | 157 | 70.40% | 114 | 57 | 171 | 13,645 | 98.76% |
| Feb 22 | 25,200 | 0.008 | 15,083 | 171.4 | 70.40% | 95 | 76 | 171 | 14,912 | 98.87% |
| Mar 22 | 25,200 | 0.008 | 14,960 | 170 | 70.40% | 114 | 76 | 190 | 14,770 | 98.73% |
| | **293,400** | | **188,573** | **2,145.10** | **70.33%** | **1,140** | **750.8** | | **186,682** | **99.00%** |
| | | | | **Performance Rate** | **70.33%** | | | | **Avg. Quality Rate** | **98.99%** |
| | | | **Availability** | **Performance** | **Quality** | **OEE** | | | | |
| | | | **64.97%** | **70.33%** | **98.99%** | **45.23%** | | | | |

Source: case company the data was collected from April 1, 2021 up to March 31, 2022

Table 4.2 shows that the data collected from the production department from April, 2021 up to March, 2022 one year planned production is 293,400 m$^3$ concrete. Next, the actual production of 188,573m$^3$ concrete was produced during the year. In addition, the actual production time of the year is 2,145.10 hours. Also, according to the data collected from the quality control and quality assurance department, 1,140m$^3$/year was reworked and 750.8m$^3$/year concrete was rejected. The total concrete production during the year was 188,573m$^3$/year, of which 2,185.4m$^3$/year was recorded due to quality.

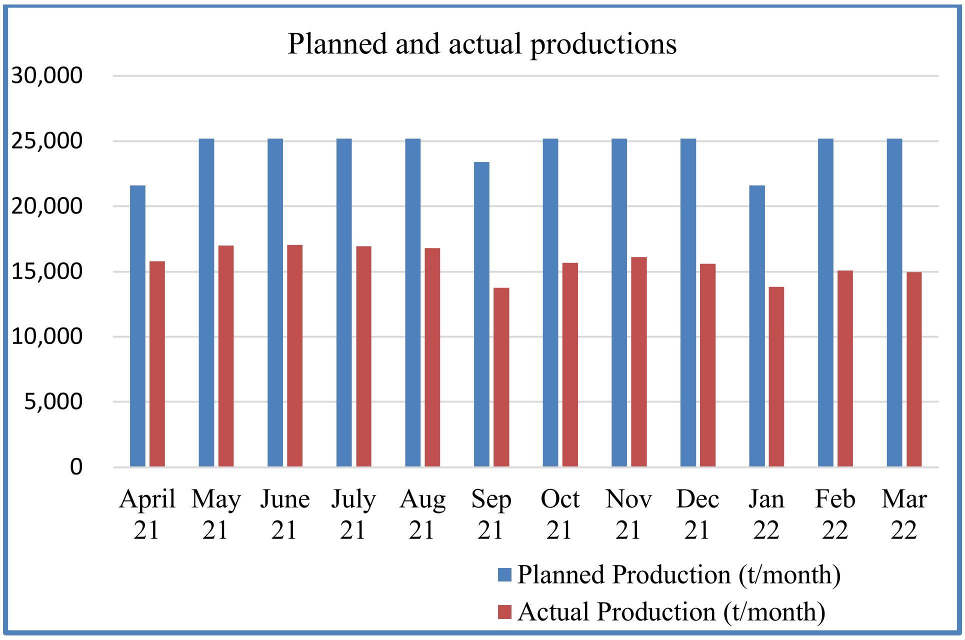



Figure 4. 4 Planned and actual production of the batching plant (in m$^3$)

Figure 4.4. Clearly explained the planned and actual production of concrete volume in which the actual production volume of the concrete was less than the planned one due to frequent machine breakdown. This case motivated to decrease the productivity of the batching plant

Table: 4. 4: Calculation of Six big Losses calculation before improvement

| Month | Downtime Loss (hour/month) | | | Speed Loss (hour/month) | | | Quality Loss (hour/month) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Breakdown loss | Setup loss | Sum | Idling & minor loss | Reduce speed loss | Sum | Reworked loss | Rejected loss | Sum |
| April 21 | 68.4 | 12 | 80.4 | 2 | 0.5 | 2.5 | 1.05 | 0.84 | 1.89 |
| May 21 | 70.3 | 16.5 | 86.8 | 2.5 | 0.6 | 3.1 | 0.84 | 0.63 | 1.47 |
| June 21 | 71 | 13 | 84 | 1.5 | 0.4 | 1.9 | 1.05 | 0.84 | 1.89 |
| July 21 | 74 | 13.5 | 87.5 | 2 | 0.6 | 2.6 | 0.84 | 0.53 | 1.37 |
| Aug 21 | 70.5 | 18.5 | 89 | 0.5 | 0.5 | 1 | 1.05 | 0.63 | 1.68 |
| Sep 21 | 84 | 19.8 | 103.8 | 0.5 | 0.8 | 1.3 | 1.05 | 0.53 | 1.58 |
| Oct 21 | 87 | 15 | 102 | 2 | 1.2 | 3.2 | 0.84 | 0.84 | 1.68 |
| Nov 21 | 83 | 14 | 97 | 3.5 | 1.5 | 5 | 1.05 | 0.53 | 1.58 |
| Dec 21 | 87 | 15.8 | 102.8 | 4 | 0.8 | 4.8 | 1.26 | 0.63 | 1.89 |
| Jan 22 | 88 | 15 | 103 | 3.5 | 1.5 | 5 | 1.26 | 0.63 | 1.89 |
| Feb 22 | 90 | 18.6 | 108.6 | 4.5 | 1.7 | 6.2 | 1.05 | 0.84 | 1.89 |
| Mar 22 | 91 | 19 | 110 | 4 | 1.9 | 5.9 | 1.26 | 0.84 | 2.1 |
| **Total** | **964.2** | **190.7** | **1154.9** | **30.5** | **12** | **42.5** | **12.6** | **8.31** | **20.91** |

Table 4.3 shows the six big losses of concrete batching plant and as shown in downtime losses, breakdown loss and setup loss are 964.2 and 190.7 hours as follows. A total of 1,154.9 hours was logged. In terms of speed loss and idling and reduce speed loss, 30.5 and 12 hours were mentioned as follows, and a total of 42.5 hours were recorded due to this problem. Next, quality loss was mentioned as 12.6 and 8.31 hours wasted every month due to rework and reject loss. The total number of hours recorded in the quality control and quality assurance section during the year is 20.9. Based on the six big losses data mentioned in this table, then a Pareto diagram is used to process the data. The breakdown loss, which had a loss/time ratio of 79.1%, was where the greatest loss/time loss occurred, according to the Pareto diagram shown below. In order to improve, the breakdown losses will be assessed.

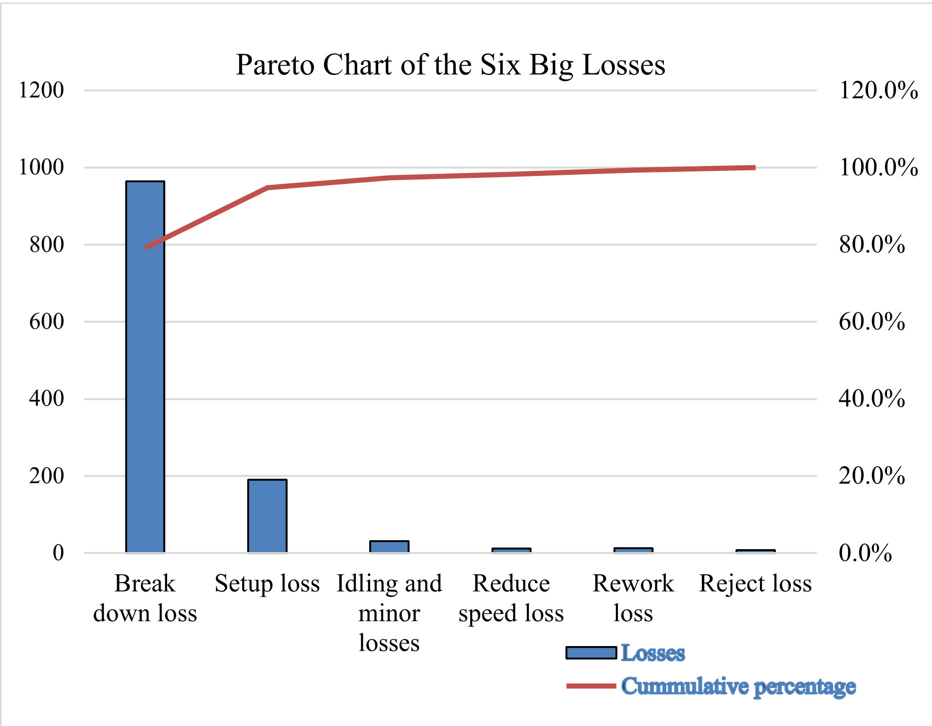



Figure: 4. 5 Pareto chart of the six big losses

Table: 4. 5, FMEA Analysis of Breakdown Losses

| Potential Failure Mode | Sev. | Potential Failure Effects | Occ. | Potential Cause of Failure | Det. | RPN | Rank |
|---|---|---|---|---|---|---|---|
| Mixer not working | 9 | Batching plant stops working (shut off) | 8 | Lack of inspection and PM, Concrete buildup inside mixer, Overload | 7 | 504 | 1 |
| Cement screw conveyor not working | 8 | Batching plant feeding interrupted | 9 | Cement buildup on the screw and lack of inspection and PM | 6 | 432 | 2 |
| Aggregate feeding system not functional | 7 | Batching plant feeding interrupted | 6 | Lack of inspection and adjustment of conveyor belt | 6 | 252 | 3 |
| Discharge door not working | 7 | Production process output interrupts | 5 | PLC system regularly not calibration and lack of PM service | 5 | 175 | 4 |
| Traditional working culture and attitude | 6 | Increase the plant breakdown and production also downs | 4 | Lack of technical knowledge of operators and technicians. | 6 | 144 | 5 |
| Spare part not available | 4 | Permanent Plant shut -off | 5 | Lack of inventory management | 5 | 100 | 6 |

As can be seen from table 4.5, the analysis result of breakdown losses indicated that the potential cause of the failure of the batching plant was as a result of the ranked causes of failures. The potential effects of the failures also clearly determined the root causes of the failure of the plant. The rank of the potential cause of failures showed that Lack of inspection and PM, Concrete buildup inside mixer, Overload was the first followed by Cement buildup on the screw and lack of inspection and PM, Lack of inspection and adjustment of conveyor belt, PLC system regularly not calibration and lack of PM service, Lack of technical knowledge of operators and technicians, and Lack of inventory management. Based on the failure mode analysis the researcher decided to calculate the OEE and to conduct a cause-and-effect analysis diagram to further define the root cause of the problem.

**OEE Calculation**

In this section, the baseline OEE value is calculated using secondary data, mainly concrete batching plant annual report data taken from maintenance and production department. The data used is data from April 1, 2021 up to March 31, 2022 G.C. The calculation of the OEE value before the improvement average annual data was based on the availability, quality, and performance rates (table 4.2). When we determine the six big losses, breakdown losses had the highest rank (964.2hrs/year). The calculation of OEE is performed using the following formula. OEE = A*P*Q, where A is the availability, P is Performance, and Q is quality rates.

In order to bring improvement in the machine availability, it is necessary to identify the root cause of the problem. By conducting a focused group discussion, which consisted of 8 workers from both the production and maintenance departments and by direct observation of the work place, a root cause analysis for the major problems contributing to down time together with the counter measures were brainstormed and categorized into appropriate themes of critical causes using 5M principles for each major causes and constructed into the fish bone diagram to show the root causes of the problems by using Microsoft Office Visio 2007, analyzed and recorded properly so that they can be used for implementation. Figure 4.3 indicates the root cause analysis for the major down time reasons and the counter measures for the critical root causes.

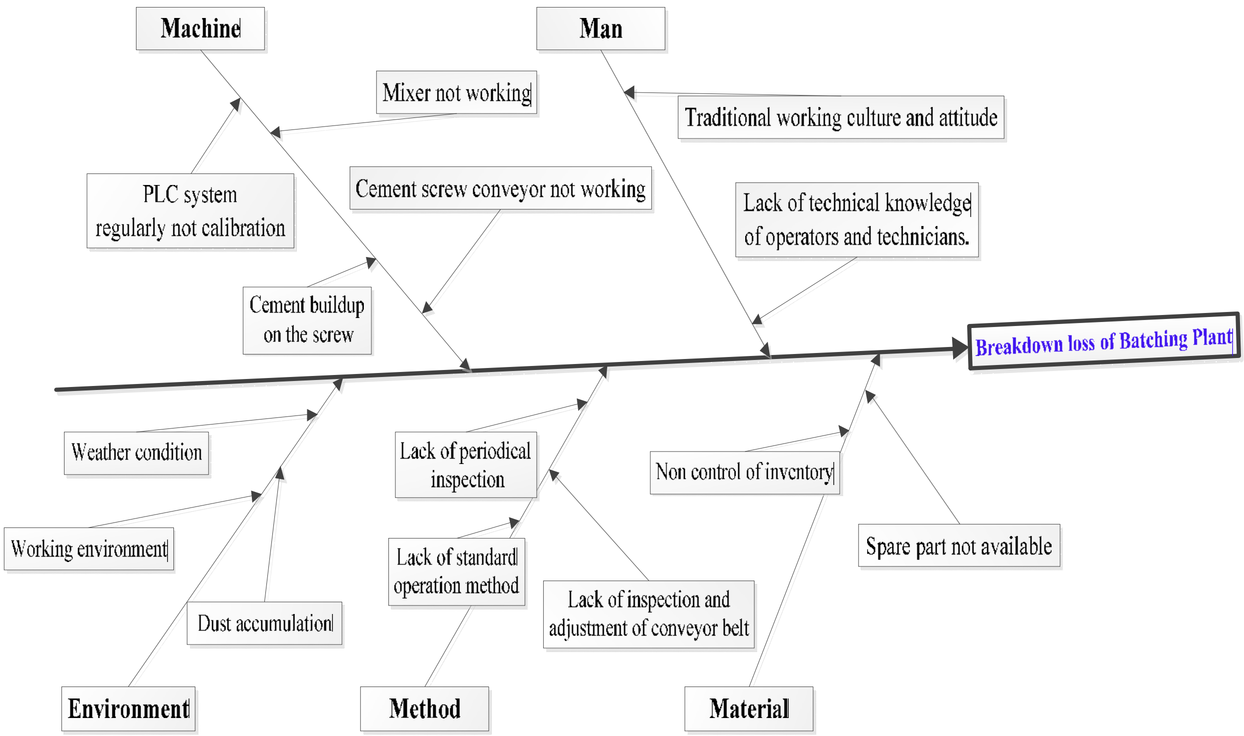



Figure: 4. 6 The Cause-and-effect diagram of case company to minimize downtime

The cause-and-effect diagram indicate that the company can minimize the downtime problems if it eliminates the identified possible causes. Based on the identified root causes of the major problems in the cause-and-effect diagram, counter measures to eliminate the root causes were discussed and summarized in table 4.3.

## 4.5. Survey of Additional Information and Result Analysis

The survey's objective was to assess the case company's maintenance procedures and its understanding of the TPM concept. To learn more about the idea of maintenance management in the organization, selected key technicians, machine operators, and maintenance staff were questioned. The study's Annex includes the structured interview questions. The acquired data was processed using SPSS to check the accuracy and dependability of the response data, and all interview findings were provided.

### 4.5.1. Degree of Focus on TPM Pillars

The next part analyses the degree of focus given to the TPM Pillars after analyzing the prior experiences of the respondents and evaluating the reliability of the results. A summary of the mean values for each TPM Pillar was computed in order to better comprehend this, as seen in table 4.5.

Table: 4. 6 Mean of the pillars

| Factor | Pillars | Over all mean | Std. Dev | Rank |
|---|---|---|---|---|
| Pillar1 | Autonomous Maintenance | 3.5201 | 0.692105 | 1 |
| Pillar 2 | Focused maintenance | 3.1562 | 0.75621 | 3 |
| Pillar 3 | Planned Maintenance | 3.3560 | 0.65823 | 2 |
| Pillar 4 | Quality Maintenance | 2.5641 | 0.58924 | 5 |
| Pillar 5 | Education & Training | 3.0892 | 0.77162 | 4 |
| Pillar 6 | Safety, health and environment | 2.1036 | 0.66359 | 7 |
| Pillar 7 | Office TPM | 2.4382 | 0.57581 | 6 |
| Pillar 8 | Development management | 1.9523 | 0.6897 | 8 |

The variability of each construct ranges from 0.5108 to 0.7721, and the mean score for each TPM elem ent ranges from 1.9523 to 3.5211. With a high total mean value of 3.3441 between them, the first four TPM Pillars, Autonomous Maintenance, Focused Maintenance, Planned Maintenance, and Training and education have stronger focus. The average mean value for the remaining four pillars, on the other hand, is 2.4295. In addition, the outcome of a TPM implementation plan can be determined by a company's ability to carry out critical maintenance activities in an organized and effective method (Ahuja and Khamba, 2008).

### 4.5.2. Dimensions of Manufacturing Performances

The success of a TPM implementation program depends on more than just formally implementing various TPM initiatives within the organization; it also depends on ensuring that the laid-out programs are moving in the right direction and that TPM implementation can yield quantifiable benefits and results. (Ahuja and Khamba, 2008).

Strategic TPM program successes can be divided into six categories, including productivity, quality, cost, delivery, safety, and morale (Nakajima, 1998). The PQCDSM (Productivity, Quality, Cost, Delivery, Safety, and Morale) benefits for early TPM implementers in Japan were also mentioned by Suzuki (1994) in his article. Describe the manufacturer's selection of emphasis among important capabilities or in short manufacturing performance, for example, which is a common theme in operational strategy studies like TPM (Ward et al., 1995).

In this research, the four basic dimensions of manufacturing performance that are going to be included are:

a) Cost (MP1)
b) Quality (MP2)
c) Availability (MP3)
d) Delivery (MP4)

A five-point Likert scale was used for the study with the following evaluation criteria: if the score value is 1 - no correlation, if the score value is 2 - nominal correlation, if the score value is 3 - some correlations, if the score value is 4 - it has a sound correlation, if the score value is 5 - widespread correlation.

## 4.6. Analyzing the significance of TPM pillars on manufacturing performance

### 4.6.1. Relationship among the factors

The relationship between TPM pillars and their contribution to various production performance dimensions were indicated based on the questionnaire. The Pearson's correlation coefficient between various TPM pillars and Manufacturing performance dimension was calculated using the bivariate correlation approach to demonstrate this relationship, as shown in Table... Finding the degree and direction of the association between two scale variables is helpful. In this instance, a key TPM aspect contributing to the perception of various production performances was determined using Pearson correlation. The pairs that are statistically most important at the 1% level of significance are those that are thought to have a strong link with one another.

Table: 4. 7 Pearson's correlation between TPM pillars and manufacturing performance dimension

| | MP1 | MP2 | MP3 | MP4 | Average |
|---|---|---|---|---|---|
| Pillar1 | 0.981** | 0.635** | 0.575** | 0.674** | 0.716 |
| Pillar 2 | 0.906 | 0.846 | 0.680 | 0.602** | 0.759 |
| Pillar 3 | 0.921** | 0.765** | 0.763** | .548** | 0.749 |
| Pillar 4 | 0.525** | 0.983** | 0.625** | 0.535** | 0.667 |
| Pillar 5 | 0.412 | 0.423 | 0.351 | 0.321* | 0.377 |
| Pillar 6 | 0.388 | 0.346 | .383* | 0.254 | 0.343 |
| Pillar 7 | 0.227 | 0.274* | 0.228 | 0.219 | 0.237 |

Source: Correlation. Pearson, Kendall, Spearman). Accessed October, 18, 2016.

## 4.7. TPM Implementation

The choice of the tool used for TPM implementation was selected depending on many factors that could give the required results. The phases for TPM implementation were explained as:

**I. The awareness creation phase:**

Regarding the work carried out in this phase, the researcher introduced the concept of TPM in a meeting attended by each department manager, starting with the company's general manager, the company's production problems over the past years, quality, and the company's disagreements with customers. Based on the one-year data collected by the researcher that it has an impact on the organization, it is everyone's responsibility to solve this problem and the researcher stated in the meeting that the organization should deal with this problem.

- The researcher stated that by taking one year's data, day by day, construction equipment downtime, maintenance frequency, increase in maintenance cost and the company is facing problems with bad relations with customers.
- The researcher applied TPM to solve this problem and it was explained to the management that it was solving this problem and the organization would be effective.
- The researcher emphasized that the concept and benefits of TPM should be communicated from the company's manager to the lower employees, and the commitment of all employees should be made. Business leaders have also pledged their commitment to TPM implementation.
- A cross-functional team (CFT) committee of experts from the maintenance department and the production department was selected.

- It was decided that a regular meeting should be held.
- It was determined that training is needed to implement TPM.
- Mechanical Engineers, Electrical Engineers, Civil Engineers, Quality engineers, operators, and maintenance professionals are made aware of the TPM researcher.
- As a researcher and member of a cross-functional team (CFT), work was done to identify which construction equipment is causing the most damage and which bottleneck equipment has problems.

**II. Organization Phase**

The main objective of this phase is to generate an organizational structure that promotes, plan, implement and supports TPM at all levels in the company. In this stage, all the possible causes for the break down and low productivity were arranged, organized.

- In this phase, the researcher identifies TPM at all levels of the organization.
- An organizational system that implements and supports TPM is done
- The researcher and the cross-functional team (CFT) identified the causes of breakdowns and low productivity.
- A joint procedure to implement TPM has been implemented in all the work units of the organization.

**III. Planning Phase**

- The researcher mentions below what he did in this phase.
- The researcher carried out the TPM implementation plan.
- Together with the researcher and the cross-functional team (CFT) at the concrete batching plant, they identified the cause of the failure. Then, to avoid the problem, a daily, weekly, monthly, and six-monthly check list has been prepared based on the service manual of the batching plant manufacturer for regular inspection and preventive maintenance.
- The budget required to implement TPM is included in this plan.
- A plan is prepared to make the materials needed to implement 5S and those that should be cleaned and disposed of convenient for work.
- Everything that the researcher and the cross-functional team should do is completed in this phase.

**IV. Implementation Phase**

After having plan for implementation, the researcher decided to initiate an implementation process throughout TPM cross functional team. This selected team worked on each machine and completing all TPM activities to improve its performance. The CFT team has to develop the right way to get things done in its own assigned place. The main criteria used for the selection of equipment suitable for TPM implementation strategy were:

- High breakdown frequency
- Importance/key equipment for the company
- Reliable with the rest of the production line high visibility within the company

The skill acquired through the CFT project was used to adjust the planning process and define resources required for TPM implementation. In addition, appropriate selection of equipment and team members in the CFT project can result in significant development in equipment performance within a relatively short period of time. At this phase the personnel training and advisement in basic controlling functions of machines were performed to make sure that employees had the ability in carrying out easy maintenance tasks and they were aware about machine functions that they were working with.

- The implementation of TPM has been done according to the researcher's plan.
- Accumulated concrete and aggregate at the concrete batching plant were cleaned and greased by experts and operators according to the plan.
- According to the training received by each operator and maintenance specialist and according to the TPM implementation plan, the researcher and the cross-functional team verified, signed, and recorded that they had fulfilled their responsibilities and obligations.
- Daily, weekly, monthly, and six-monthly cleaning and preventive maintenance are done according to the concrete batching plant checklist.
- According to the training given to the operators and assistants, it was implemented by the cross-functional team so that they did everything that should be done at the concrete batching plant.

**V. Assessment Phase**

This phase extents to the standards and learning attained by training at the phases of implementation and it’s the time for operators to start implementing basic investigation and maintenance tasks autonomously. The objectives of the assessment system were to:

- Validate the progress made in TPM improvement activities
- Calculate the level of TPM maturity in the case company
- Explain areas of strength and weakness in the implementation process
- Integrate TPM improvement projects with the organization’s business plan
- Assess introduce readiness to apply for a plant maintenance honor

In this phase, results were compared with those of earlier stages and document the achievements of TPM strategy. TPM strategy works using the concept of "I operate and I fix", and neglecting the concept of, "I operate and you fix". That's because this concept invites external maintenance staff to bring the machine back to its operating conditions.

- Along with the researcher and cross-functional team, the work done during the TPM implementation was evaluated, and the changes and weaknesses were improved every month, and the strengths were further improved. Therefore, the researcher conducted the evaluations below.
- A comparison is made between before and after TPM implementation. The comparisons made are Availability, performance, quality, and Overall Equipment Effectiveness (OEE).
- The six big losses before and after TPM were compared, and the researcher monitored them every month to find out which one should be reduced.
- Based on the obtained results, continuous and consistent improvement is carried out.

### 4.7.1 The Steps for TPM Implementation

The implementation of TPM is generally done in five steps: identifying a pilot area, restoring equipment to prime operating condition, measuring OEE, addressing and reducing major losses, and implementing planned maintenance.

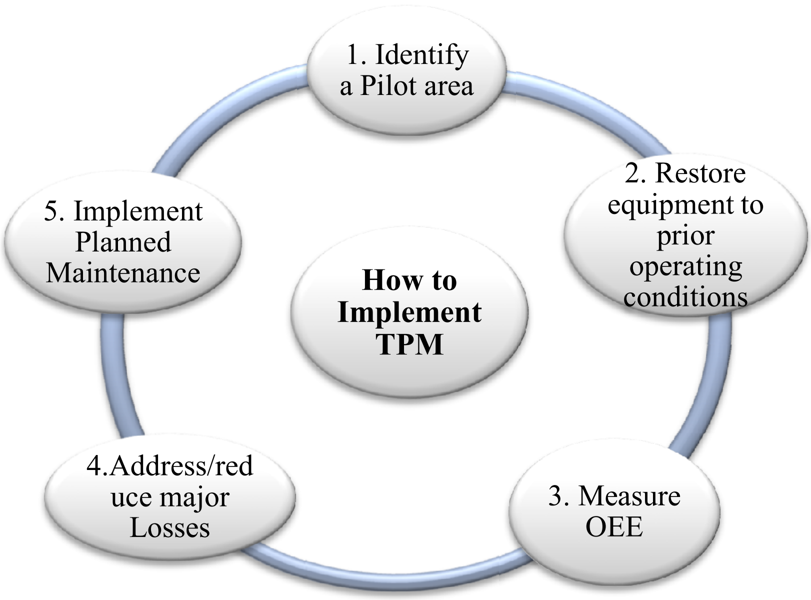



Figure: 4. 7 How to implement TPM (Source: (Lee Cooke, 2000))

The researcher also applied the pillars of TPM for the successful implementation and to render the problems encountered in the case company (figure 4.7).

**Step One: Identify Pilot Area:** In this step the target equipment for the pilot TPM program was selected. There are three reasonable ways to approach this selection.

Table: 4. 8 Approaches for pilot area identifications in current working organization

| Which Equipment? | Pros | Cons |
|---|---|---|
| Easiest to Improve | ▪ The best chance for a "quick win"<br>▪ More tolerant of insufficient of TPM experience. | ▪ Less profitable than improving constrained equipment.<br>▪ Does not as thoroughly "test" the TPM process as the other alternatives. |
| Constraint/Bottleneck | ▪ Instantaneously raises overall output.<br>▪ Offers the quickest payoff. | ▪ Working on a crucial asset as a test project carries a greater risk.<br>▪ Equipment may become offline more frequently than anticipated as it is enhanced. |
| The Most Troublesome | ▪ Operator support for improving this equipment will be strong.<br>▪ Solving recognizable issues will increase support for the TPM initiative. | ▪ Less profitable than improving constrained equipment.<br>▪ Unsettled issues are frequently unsettled for a cause, such as the difficulty in obtaining satisfactory solutions. |

Additional procedures include:

- The Easiest to improve equipment is typically the best option for a business with limited TPM experience and/or support (whether through internal workers or external consultants).
- The Constraint/Bottleneck equipment is typically the best option for a company with moderate to strong TPM experience and/or support (whether through internal people or external consultants). By creating temporary stock and taking other steps to ensure that unexpected stop times may be accepted, the aim is to reduce possible risk.
- Teams frequently incline toward choosing the equipment with the most problems. However, this is rarely the best option (unless it also happens to be the bottleneck or constraint).

Make sure to involve the entire range of associated employees (operators, maintenance staff, and managers) in the decision process and work hard to forge a group agreement regarding the equipment selection choice in order to build a broad base of support for the TPM project.

Create a local visual focus for the project (such as a project board) once the pilot area has been decided upon where plans and development updates can be posted.

**Step Two: Restore Equipment to Primary Operating Condition:** The 5-S system and autonomous maintenance are the two key components of the idea of getting equipment back into top working condition. Participants in TPM should first become familiar with the 5-S system, which stands for organize, cleanliness, orderliness, standardization, and sustainability. The equipment was cleaned and/or prepared for improved operation in this step. Initiate a 5S program first, involving maintenance technicians as well as operators.

Table: 4. 9 Initiation of 5-S program for operators and maintenance personnel in current working organization

| Item | Description |
|---|---|
| Picture | Take pictures of the equipment in its initial condition and publish them on the project board. |
| Clear the Area | Remove any trash, unnecessary tools, and other objects from the area. |
| Organize | Place the remaining equipment and materials on shadow boards (boards with visual signals such as outlines). |
| Clean Up | Clean the equipment and the surrounding area completely, including any traces of spills or leaks. |
| Photograph | Take pictures of the equipment in its upgraded state and put them on the project board. |
| Checklist | For the area, make a basic 5S checklist (generating Standardized Work for the 5S process). |
| Audit | To ensure that the 5S checklist is being followed, schedule a recurring audit (at first daily, then weekly). Update the checklist as necessary during the audit to keep it current and applicable. Make sure audits are inspiring and upbeat (approach them as a training activity). |

The next step is to start a program for autonomous maintenance. Work to reach an understanding between operators and maintenance staff regarding which recurrent duties operators can successfully complete. To raise the competence level of operators, it was frequently be necessary to give them some short training.

Table: 4. 10 Initiation of an autonomous maintenance program

| Item | Description |
|---|---|
| Inspection Points | Identify and record important inspection points (every wear component should be included). As a visual help, think about making an inspection point's map. |
| Visibility | If inspection points are hidden, replace transparent guarding with transparent guarding (where possible and safe to do so). |
| Set Points | List all set points and the settings that correspond to them. As a visual help for inspection and auditing, take into account marking settings immediately on the equipment. |
| Lubrication Points | Recognize and record each lubrication point. To prevent adding new sources of unplanned stop time, schedule lubrication to happen during changeovers or other planned stops. Where possible and safe to do so, think about externalizing lubrication sites that are challenging to reach or that involve stopping the equipment in question. |
| Operator Training | Operators should be instructed to alert line supervisors to any anomalies or new conditions. |
| Create Checklist | For all inspection, set point, lubrication, and other operator-controlled maintenance operations (forming Standardized Work for the Autonomous Maintenance process), create a straightforward Autonomous Maintenance checklist. |
| Audit | To ensure that the Autonomous Maintenance checklist is being followed, schedule a recurring audit (at first daily, then monthly). Update the checklist as necessary during the audit to keep it current and applicable. Make sure audits are inspiring and upbeat (approach them as a training activity). |

**Step Three: Start Measuring OEE:** This stage involves setting up a mechanism to monitor OEE for the intended equipment. This system is manual. The recording system's scope must include tracking of unscheduled stop time reason code. Unplanned stops were the main cause of losses for the majority of pieces of equipment. As a result, it is highly advised to classify every unexpected halt occurrence to gain a clear understanding of where valuable time is being lost. A category for "unallocated" stop time, or stop time where the cause is ambiguous, is also advised to be included. With manually recorded OEE, it is especially crucial to provide a category for unallocated halt time. When the stop time cause is unclear, it gives operators a safe alternative, which increases accuracy.

For at least two weeks, data should be obtained to find recurring causes of unplanned equipment downtime as well as the effects of brief stops and sluggish cycles. Every shift, check the data to make sure it is accurate and to confirm that the real reasons for unscheduled stop times are being recorded. Based on the steps followed in the study and assigned teams, the OEE was calculated from the batching plant and supportive equipment operating conditions at site.

**Step Four: Address Major Losses:** The main causes of spent productive time are addressed in this stage. It introduces the Focused Improvement (often referred to as Kaizen) TPM concept.

Table: 4. 10a Focused Improvement (often referred to as Kaizen) TPM on case company

| Item | Description |
|---|---|
| Select Losses | Choose one significant loss to rectify based on equipment-specific OEE and stop time data. The main loss that is chosen should typically be the biggest cause of unscheduled halt time. |
| Create Team | Form a multidisciplinary team to solve the issue. Four to six individuals (supervisors, maintenance staff, and operators) who have the most expertise with the equipment should be a part of this team. They were probably going to get along well. |
| Collect Information | Gather thorough data on the issue's symptoms, including observations, tangible evidence, and photographic proof. Use an Ishikawa (fishbone) diagram to collect observations at the apparatus. |
| Organize | Plan a systematic problem-solving session to: a) identify the problem's likely causes; b) compare those causes to the information gathered; and c) choose the best solutions. |
| Schedule | Planned stop time should be used to apply the suggested fixes. When implementing fixes, make sure to follow any current change control procedures. |
| Restart | Restart production and assess the fixes' efficacy over a suitable time frame. Document any procedure adjustments if they are sufficiently successful, and then move on to the following large loss. If not, gather more details and plan another structured problem-solving meeting. |

OEE data was meticulously examined every shift during this phase to track the progress of losses that had previously been remedied as well as broader productivity gains and compared with the previous calculated value.

**Step Five: Introduce Proactive Maintenance Techniques:** This stage introduces the TPM idea of planned maintenance by including proactive maintenance practices into the maintenance program.

➢ First, list all the parts that call for preventive maintenance:

Table: 4. 10b Focused Improvement Proactive Maintenance Techniques TPM on case company

| Item | Description |
|---|---|
| Components that Wear | All components that experience wear should have been identified and recorded in Step Two as inspection points. Replace worn components with low- or no-wear alternatives. |
| Components that Fail | All components that are known to frequently fail should be identified and documented. |
| Stress Points | To put a greater spotlight on the equipment stress spots, think about using vibration analysis and/or thermography, which is. |

➢ The next step is to set up the first proactive maintenance intervals:

Table: 4. 10c Focused Improvement Proactive Maintenance Techniques

| Item | Description |
|---|---|
| Wear – Based | Establish the baseline replacement interval and current wear level for wear components (in some circumstances, an Autonomous Maintenance check performed in Step Two may cause a replacement to occur earlier). |
| Based on Predicted Failure | Establish a baseline (predicted) failure interval for components that are prone to failure. |
| Time- Based | Establish a baseline a proactive replacement strategy for those components that are prone to wear and failure. Instead of utilizing "Calendar Time" as the interval time base, think about using "Run Time." |
| Order-Based Work | Using the planned maintenance schedule as a guide, establish a uniform procedure for creating work orders. |

➢ Next, develop a feedback system to improve the intervals between maintenance.

Table: 4. 10d feedback system to improve the intervals between maintenance on case company

| Item | Description |
|---|---|
| Log component | For each component that is prone to wear and failure, create a Component Log sheet. Record each time a component is replaced together with details about the status of the component at the time (such as wear amount, "component failed," "no observable issues," etc.). |
| Monthly Audit | Conduct a monthly Planned Maintenance audit to ensure that the Planned Maintenance Schedule is being followed, the Component Log sheets are being kept up to date, and all new entries in the Component Log are reviewed and |

| | |
|---|---|
| | maintenance intervals are adjusted as necessary. Make sure audits are inspiring and upbeat (approach them as a training activity). |
| Adjustments to Maintenance Intervals | Consider modifying the maintenance schedule whenever a component needs to be replaced on an unscheduled basis. Consider include the component if it isn't already on the planned maintenance schedule. |
| Analyzing components | Plotting thermography and vibration analysis data over time can reveal new difficulties and concerns. |

## 4.8. Result Analysis of TPM Implementation

The implementation of TPM program creates a shared responsibility for equipment that encourages greater involvement by plant floor workers. In the right environment this can be very effective in improving productivity (increasing uptime, reducing cycle time, and eliminating defects). TPM implementation improves the equipment availability, performance, and quality rates of each equipment of the case company. Productivity of equipment is the sum of all parts of the system in terms of availability, performance, quality, and effectiveness. As can be seen from Table 4.11 up to 4.13 the improvement values clearly showed the current conditions of the company equipment productivity rates.

Table: 4. 11 availability rate after implementation

| Month | Number of working days | Working hours/day | Planned Production Time (hr./month) | Downtime (hr./month) | Actual Production Time (hr./month) | AR |
|---|---|---|---|---|---|---|
| April 22 | 26 | 10 | 260 | 108 | 152 | 58.46% |
| May 22 | 28 | 10 | 280 | 102.4 | 177.6 | 63.43% |
| June 22 | 28 | 10 | 280 | 94 | 186 | 66.43% |
| July 22 | 28 | 10 | 280 | 92.2 | 187.8 | 67.07% |
| Aug 22 | 28 | 10 | 280 | 89.6 | 190.4 | 68.00% |
| Sep 22 | 26 | 10 | 260 | 87.4 | 172.6 | 66.38% |
| Oct 22 | 28 | 10 | 280 | 88.5 | 191.5 | 68.39% |
| Nov 22 | 28 | 10 | 280 | 86.8 | 193.2 | 69.00% |
| Dec 22 | 28 | 10 | 280 | 82.6 | 197.4 | 70.50% |
| Jan 23 | 26 | 10 | 260 | 84 | 176 | 67.69% |
| Feb 23 | 28 | 10 | 280 | 74.7 | 205.3 | 73.32% |
| Mar 23 | 28 | 10 | 280 | 72.4 | 207.6 | 74.14% |
| **Total** | **330** | **120** | **3,300.00** | **1,062.60** | **2,237.40** | 67.80% |
| | | | | | Average Availability | **67.74%** |
| Source: case company data collected from April 1, 2022 up to March 31, 2023 | | | | | | |

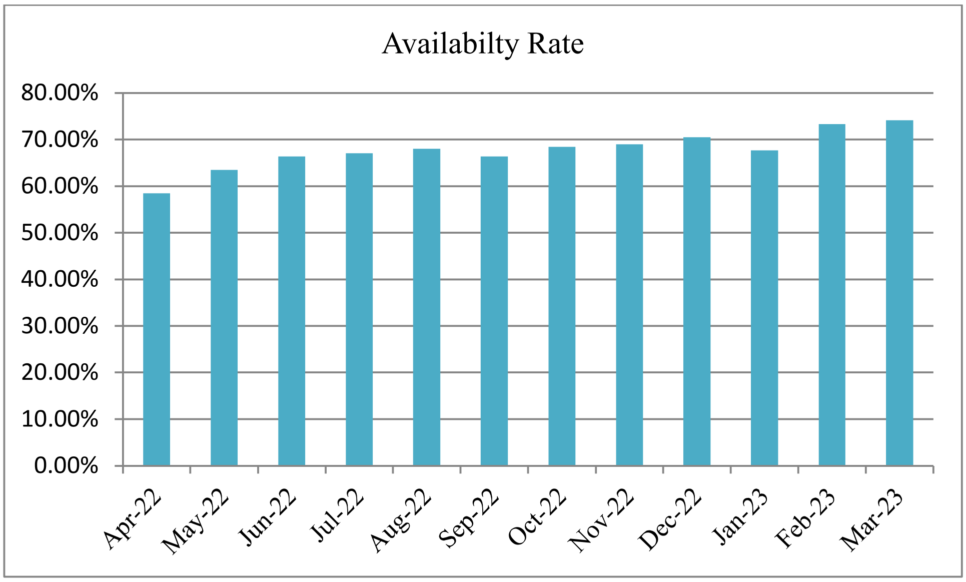
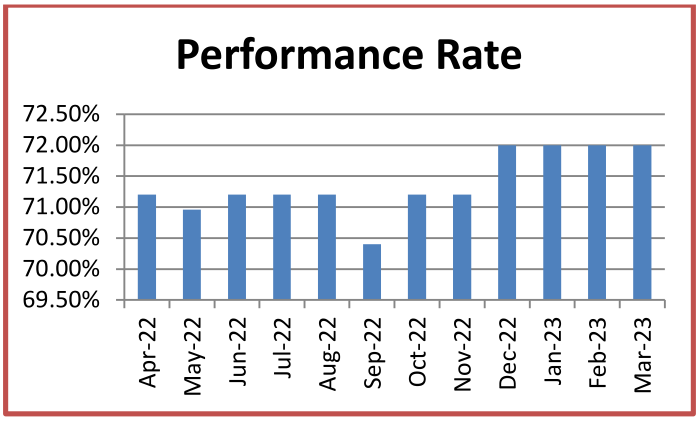



Figure: 4. 8 Availability rate of the concrete batching plant from April 1, 2022 to March 31, 2023

Table: 4. 12 OEE after TPM implementation

| Month | Planned Production ($M^3$/month) | Ideal cycle time | Actual Production ($M^3$/month) | Actual Production Time (hr./month) | Performance Efficiency | Reworked ($M^3$/month) | Rejected ($M^3$/month) | Total defect ($M^3$) | Quality produced ($M^3$) | Quality Rate |
|---|---|---|---|---|---|---|---|---|---|---|
| April 22 | 21,600 | 0.008 | 13,528 | 152 | 71.20% | 114 | 82 | 196 | 13,332 | 98.55% |
| May 22 | 25,200 | 0.008 | 15,753 | 177.6 | 70.96% | 116 | 81 | 197 | 15,556 | 98.75% |
| June 22 | 25,200 | 0.008 | 16,554 | 186 | 71.20% | 114 | 76 | 190 | 16,364 | 98.85% |
| July 22 | 25,200 | 0.008 | 16,714 | 187.8 | 71.20% | 95 | 57 | 152 | 16,562 | 99.09% |
| Aug 22 | 25,200 | 0.008 | 16,946 | 190.4 | 71.20% | 76 | 47.6 | 123.6 | 16,822 | 99.27% |
| Sep 22 | 23,400 | 0.008 | 15,189 | 172.6 | 70.40% | 95 | 57 | 152 | 15,037 | 99.00% |
| Oct 22 | 25,200 | 0.008 | 17,043 | 191.5 | 71.20% | 76 | 76 | 152 | 16,891 | 99.11% |
| Nov 22 | 25,200 | 0.008 | 17,195 | 193.2 | 71.20% | 95 | 47.6 | 142.6 | 17,052 | 99.17% |
| Dec 22 | 25,200 | 0.008 | 17,766 | 197.4 | 72.00% | 76 | 57 | 133 | 17,633 | 99.25% |
| Jan 23 | 21,600 | 0.008 | 15,840 | 176 | 72.00% | 57 | 57 | 114 | 15,726 | 99.28% |
| Feb 23 | 25,200 | 0.008 | 18,477 | 205.3 | 72.00% | 95 | 47.6 | 142.6 | 18,334 | 99.23% |
| Mar 23 | 25,200 | 0.008 | 18,684 | 207.6 | 72.00% | 57 | 47.6 | 104.6 | 18,579 | 99.44% |
| | 293,400 | 0.008 | 199,689 | 2,237.40 | 856.56% | 1,066.00 | 733.4 | 1,799.40 | 197,889 | 99.10% |
| | | | | **Performance Rate** | **71.38%** | | | | **Avg. Quality Rate** | **99.08%** |
| **OEE** | | | **Availability** | **Performance** | **Quality** | **OEE** | | | | |
| | | | **67.74%** | **71.38%** | **99.08%** | **47.91%** | | | | |

**Source:** case company data was collected from April 1, 2022 up to March 31, 2023




Figur4. 9 Performance rate of the concrete batching after TPM implementation

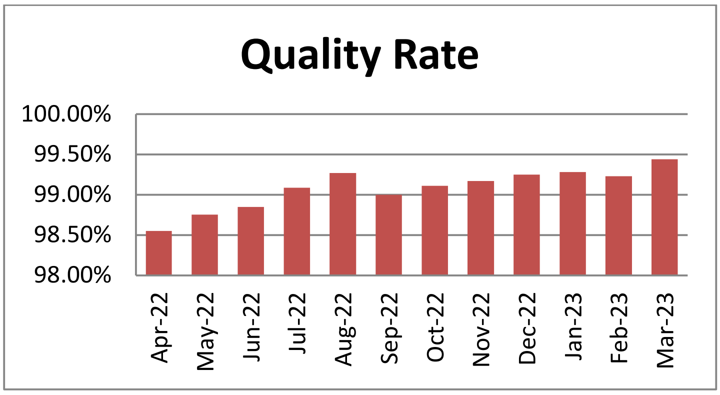



*Figure: 4. 10: Quality rate of the batching plant after TPM implementation*

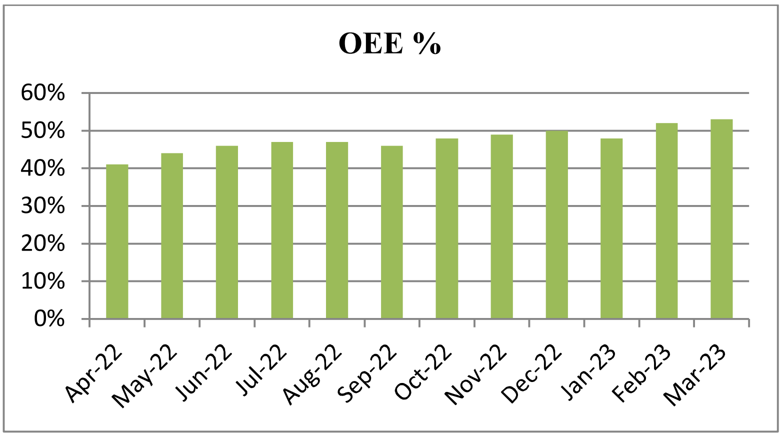



Figure4. 11Overall equipment effectiveness of batching plant after TPM implementation

Table 4: 13 Calculated Six Big Losses after TPM Implementation

| Month | Downtime Loss (hour) | | | Speed Loss (hour) | | | Quality Loss (hour) | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Breakdown loss** | **Setup loss** | **Sum** | **Idling & minor loss** | **Reduce speed loss** | **Sum** | **Reworked loss** | **Rejected Loss** | **Sum** |
| April 22 | 90 | 18 | 108 | 4.5 | 0.5 | 5 | 1.26 | 0.91 | 2.17 |
| May 22 | 88.4 | 14 | 102.4 | 3.2 | 0.6 | 3.8 | 1.28 | 0.89 | 2.17 |
| June 22 | 79 | 15 | 94 | 3.6 | 0.8 | 4.4 | 1.26 | 0.84 | 2.1 |
| July 22 | 78 | 14.2 | 92.2 | 0.5 | 1.5 | 2 | 1.05 | 0.63 | 1.68 |
| Aug 22 | 76 | 13.6 | 89.6 | 1.5 | 0.6 | 2.1 | 0.84 | 0.52 | 1.36 |
| Sep 22 | 75 | 12.4 | 87.4 | 3 | 0.4 | 3.4 | 1.05 | 0.63 | 1.68 |
| Oct 22 | 75.5 | 13 | 88.5 | 1.2 | 0.8 | 2 | 0.84 | 0.52 | 1.36 |
| Nov 22 | 74 | 12.8 | 86.8 | 1.5 | 0.6 | 2.1 | 1.05 | 0.63 | 1.68 |
| Dec 22 | 71 | 11.6 | 82.6 | 0.8 | 0.7 | 1.5 | 0.84 | 0.63 | 1.47 |
| Jan 23 | 72 | 12 | 84 | 0.6 | 0.5 | 1.1 | 0.63 | 0.52 | 1.15 |
| Feb 23 | 65 | 9.7 | 74.7 | 0.5 | 0.6 | 1.1 | 0.53 | 0.52 | 1.05 |
| March 23 | 62.8 | 9.6 | 72.4 | 0.6 | 0.5 | 1.1 | 0.63 | 0.52 | 1.15 |
| **Total** | **906.7** | **155.9** | **1,062.60** | **21.5** | **8.1** | **29.6** | **11.26** | **7.76** | **19.02** |

Source: analysis on the above data source of case company

### 4.8.1. Implementation Costs

The cost of TPM implementation in the case company includes all expenses incurred during the overall process of the TPM activities as shown in table 4.14.

Table 4. 14: Cost of TPM implementation

| | **a. Manpower Expenses** | | | | | |
|---|---|---|---|---|---|---|
| S/No. | Title | UOM | Qty. | Monthly (birr) | Annual (birr) | Remark |
| 1 | Mechanical Engineer | No. | 1 | 17,278.0 | 207,336.0 | |
| 2 | Electrical Engineer | No. | 1 | 16,865.0 | 202,380.0 | |
| 3 | Grease boys | No. | 2 | 7,192.0 | 172,608.0 | |
| 4 | Daily Labors | No. | 3 | 11,700.0 | 140,400.0 | |
| | | | | **Sub Total** | **722,724.0** | |
| | **b. Cost of Workshop Tools and Accessories** | | | | | |
| S/No. | Part description | UOM | Qty. | Unit Price (birr) | Total Cost (birr) | |
| 1 | Mechanical hand tools | Set | 1 | 98,760.0 | 98,760.0 | |
| 2 | Multi-meter | Pcs | 1 | 38,490.0 | 38,490.0 | |
| 3 | Oxyacetylene welding tip | Set | 1 | 23,256.0 | 23,256.0 | |
| 4 | Oxygen cylinder | Pcs | 1 | 9,755.0 | 9,755.0 | |
| 5 | Acetylene cylinder | Pcs | 1 | 9,755.0 | 9,755.0 | |
| 6 | Grease gun | Pcs | 2 | 1,450.0 | 2,900.0 | |
| 7 | Hcl chemical | Liter | 240 | 78.50 | 18,840.0 | |
| 8 | Chisel | Pcs | 4 | 235.0 | 940.0 | |
| | | | | **Sub Total** | **202,696.0** | |
| | **c. Training Cost** | | | | | |
| S/No. | Description | UOM | Qty. | Unit Cost (birr) | Total Cost (birr) | Remark |
| 1 | Operators | No. | 3 | 5,200.0 | 15,600.0 | Including facilities |
| 2 | Technicians | No. | 7 | 7,300.0 | 35,000.0 | |
| | | | | **Sub Total** | **51,100.0** | |
| | | | | **Grand Total (a+b+c)** | **976,520.0** | |

Source: analysis on the above data of case company

Table 4.14 shows that the total cost incurred for the implementation of TPM in the case company was birr 976,520.00. The company batching plant produced 186,682 $m^3$/year of concrete before the implementation of TPM, and 197,889$m^3$/year of concrete after the implementation in which the production increased by 11,207$m^3$/year of concrete.

## 4.9. TPM Implementation Framework

To give operators a greater sense of ownership over their equipment and to spark their interest in their jobs, TPM implementation had to be introduced. By actively participating, operators can attain the goal of maximizing production. The figure below shows the suggested process for implementing TPM, which was built using extensive literature review and questionnaire data.

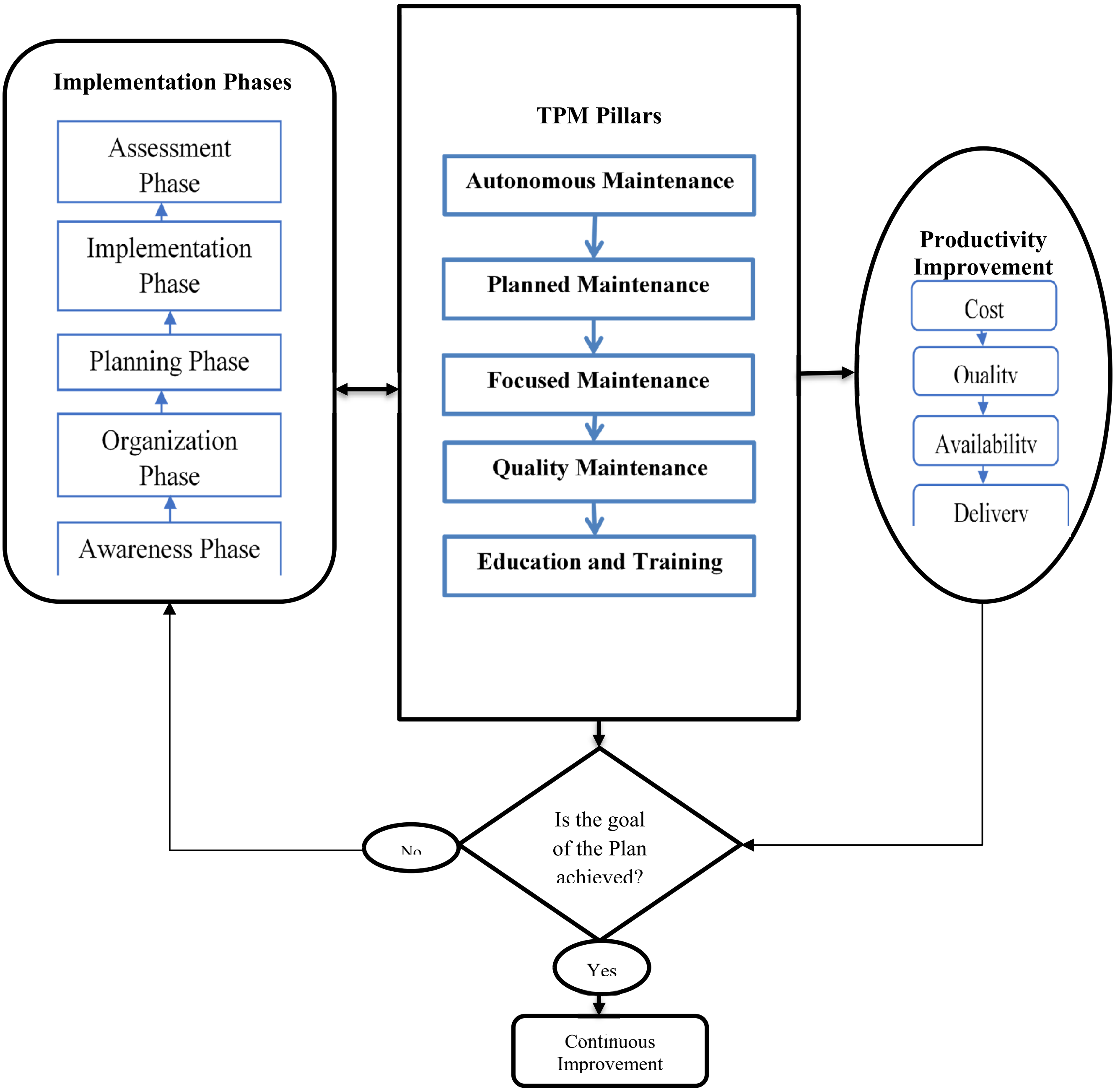



Figure: 4. 12, TPM Implementation Framework

The productivity of concrete batching plant can be improved through whole and active participations of key workers. The initiation and introduction of TPM in the case company was essential to increase awareness labor as well as equipment productivity. Top management commitment for the implementation and supporting the team proactively could also help the improvement strategy.

### 4.10. Challenges Faced in TPM implementation

According to Sharma, K. et al, (2012), many challenges are faced in TPM implementation and one of these challenges is that there is no quick way for implementation and the period of starting to implement TPM till the appearance of improvement may last for one to three years depending on certain factors such as:

- The size of the organization
- Type of production system
- Management and the way of implementation
- People and effort

Some organizations may not implement all the pillars of TPM and the choice of the rated tool depends on many factors. Challenges that may be faced during TPM implementation include (Eswaramurthi, K. G., and Mohanram, P. V. 2013):

- Difficulty in understanding the linkages between the eight pillars
- No sufficient resources (people, money, time, etc.) and assistance provided
- Lack of management support and understanding of the strategy
- Lack of sufficient training
- Lack of structure and relation to strategic needs
- Lack of necessary mixture of skills and experienced in TPM team
- Typically, people show strong resistance to change

# CHAPTER FIVE
# 5. CONCLUSION AND RECOMMENDATIONS

## 5.1. Conclusion

The purpose of this study was to improve the effectiveness of construction equipment by selecting TPM Pillars and evaluate their impact on manufacturing performance features. The questionnaire was done on the Dugda Construction PLC. According to the findings and discussion, autonomous maintenance has received the most attention under the TPM Pillar, whereas development management has received the least attention. This study looked into how the TPM Pillars emphasis on manufacturing performance dimensions affected those aspects in Dugda Construction PLC. After reviewing the issues at the case company, four manufacturing performance dimensions have been categorized for this use. The association between various TPM pillars and manufacturing performance has been supported by empirical research. After implementation of TPM in the company, availability, performance, quality, and OEE was increased from 64.97% to 67.74%, 70.33% to 71.38%, 98.99% to 99.08%, and 45.23% to 47.91% respectively. The implementation also increased the concrete batching plant production by 11,207$m^3$/year. The findings demonstrated that these TPM elements are important for company operations in terms of cost reduction, improved equipment availability, strong delivery, higher levels of productivity, and more flexibility.

## 5.2. Recommendations

To minimize downtime and increase the availability of machinery and equipment, the autonomous and scheduled maintenance pillars, when properly implemented and continually upgraded, play a crucial role. The company ought to think about utilizing these chosen pillars to fix the equipment's existing critical performance issues. According to the analysis, the degree of downtime and machine idle time was high enough to cost the business time and material. Because employees are equipped with the knowledge and motivation to follow the process for continuous improvement, the TPM pillars of Focused maintenance and Training and Education help to enhance the process and reduce downtimes. The company has to establish an approach to evaluate OEE for each equipment and machine in terms of availability losses, performance losses, and quality losses. Because most disruptions emerge from messy machines and because cleaning is one of the most effective methods to look for abnormalities and deal with them at an early stage, the company must concentrate on the series implementation of 5S so that equipment should be kept clean.  Since skill gaps were a contributing factor to machine breakdown, the company has to put a high priority on training and education to establish a learning environment within the company. It needs to improve cooperation between the production and maintenance departments in the company and should focus on implementing technicians-initiated daily maintenance, which includes cleaning, lubrication, and inspections, as well as improvement initiatives that involve just low equipment repair.

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# Annex I

## Addis Ababa University

## Addis Ababa Institute of Technology

## School of Mechanical and industrial Engineering

## Industrial Engineering Stream

**Questionnaire on Overall Equipment Effectiveness Improvement through Implementation of Total Productive Maintenance: A Case Study on Dugda Construction Plc**.

**Dear Respondent**,

This survey focuses on the topic of improving the overall equipment effectiveness of Construction Equipment by Using Total Productive Maintenance. This questionnaire's primary goal is to gather data regarding the manufacturing performance and overall Total Productive Maintenance experience of our company.

Any information you give will be kept in strict confidence because it is only used for academic purposes.

Your kind collaboration is highly appreciated!

### 1. General Information

i. Gender: Male ☐ Female: ☐

ii. Age: 20-30 ☐ 31-40 ☐ 41-50 ☐ 50+ ☐

iii. Current position: Managerial ☐ Non-managerial ☐

iv. Educational Background (tick only the highest level you have):

v. Masters ☐ Bachelors ☐ Diploma/TVET ☐ High school Completed ☐

vi. Years of experience: 1-2 ☐ 3-5 ☐ 6-10 ☐ 11-15: ☐

16-20 ☐ above 20: ☐

## 2. Dimensions of TPM Pillars

| **Autonomous Maintenance (Pillar-1)** | Strongly Agree (5) | Agree (4) | Neutral (3) | Dis-agree (2) | Strongly dis-agree (1) |
|---|---|---|---|---|---|
| 1.1.The organization has implemented 5S initiatives. | | | | | |
| 1.2.The organization places a strong emphasis on organizing all equipment and supplies. | | | | | |
| 1.3.The implementation of the cleaning, lubrication, and tightening criteria is proceeding well. | | | | | |
| 1.4.Operators collaborate in teams that address issues to enhance manufacturing procedures. | | | | | |
| 1.5. Any individual awareness of production operators' ownership of equipment | | | | | |
| 1.6.Visual controls are organized and used, such as a TPM activity board and labels. | | | | | |
| **Focused improvement (Pillar-2)** | Strongly Agree (5) | Agree (4) | Neutral (3) | Dis-agree (2) | Strongly dis-agree (1) |
| 2.1. The company has previously provided you with training sessions related to the task you | | | | | |
| 2.2. maintaining essential equipment condition and restoring it to ideal | | | | | |
| 2.3. Eliminating even little equipment flaws is the goal of | | | | | |
| 2.4. Employees have easy access to information about productivity | | | | | |
| 2.5. Utilizing fishbone, RC, Pareto, 5 Whys, and FMA diagrams to identify and eliminate productivity | | | | | |
| 2.6. TPM is a tool that the company uses to improve manufacturing | | | | | |
| **Planned maintenance (Pillar-3)** | Strongly Agree (5) | Agree (4) | Neutral (3) | Dis-agree (1) | Strongly dis-agree (1) |

| | | | | | |
|---|---|---|---|---|---|
| 3.1. There is a process in place for routinely inspecting machinery and equipment, which is based on the inspection program. | | | | | |
| 3.2. Equipment and machinery are cleaned regularly. | | | | | |
| 3.3. PM Check sheets specifying PM work for each equipment are | | | | | |
| 3.4. Monitoring, analysis, and prevention of recurrence of machine failure are done. | | | | | |
| 3.5. The inspection of machinery and equipment is covered by a | | | | | |
| 3.6. Tools and cleaning supplies are available whenever needed. | | | | | |
| 3.7. Regular and scheduled inspections are performed on control devices and equipment. | | | | | |
| **Quality maintenance (Pillar-4)** | Strongly Agree (5) | Agree (4) | Neutral (3) | Dis-agree (2) | Strongly dis-agree (1) |
| 4.1.The maintenance team is skilled in managing maintenance tasks in a timely manner. | | | | | |
| 4.2.Our current daily effort centers on reducing and eliminating | | | | | |
| 4.3.We are working here with a cause-oriented strategy rather | | | | | |
| 4.4.Lack of consumer satisfaction due to insufficient maintenance | | | | | |
| 4.5.Poor maintenance handling results in scraps and quality | | | | | |
| **Education and Training (Pillar-5)** | Strongly Agree (5) | Agree (4) | Neutral (3) | Dis-agree (2) | Strongly dis-agree (1) |
| 5.1. All personnel received TPM training that covered an introduction to the TPM | | | | | |
| 5.2.Production workers receive training in routine PM tasks, | | | | | |
| 5.3.Employees are trained to handle a variety of tasks | | | | | |
| 5.4.Employees at this factory are only taught how to perform one | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| 5.5.A staff development program is available that focuses on improving employees' technical, problem-solving, and teamwork skills, among other | | | | | |
| **Early Equipment Management (Pillar-6)** | Strongly Agree (5) | Agree (4) | Neutral (3) | Dis-agree (2) | Strongly dis-agree (1) |
| 6.1. A new product can quickly reach the required quality and requires less time to produce. | | | | | |
| 6.2.Low levels of scrap are produced during the addition of | | | | | |
| 6.3.No breakdown or downtime is recorded when a new machine is | | | | | |
| 6.4.When a new machine is starting up, the company's capacity to supply in sufficient volume and at the desired quality is enough. | | | | | |
| 6.5.You think that the production performance is not primarily affected by new installations and new product development. | | | | | |
| **Office TPM (Pillar-7)** | Strongly Agree (5) | Agree (4) | Neutral (3) | Dis-agree (2) | Strongly dis-agree (1) |
| 7.1. We know that Usually office work will not affect the | | | | | |
| 7.2. The interaction with the administrative peoples does not determines how effective of the shop floor | | | | | |
| 7.3. We have noticed that effectiveness of logistic affects the performance of shop floor | | | | | |
| 7.4. The decision making from the office is good to facilitate | | | | | |
| 7.5. The organization in the office is clearly making it effective in helping the shop floor. | | | | | |
| **Safety, Health, and the Environment (Pillar-8)** | Strongly Agree (5) | Agree (4) | Neutral (3) | Dis-agree (2) | Strongly dis-agree (1) |

| | | | | | |
|---|---|---|---|---|---|
| 8.1. We feel safe in our day to day activity and it affects our performance | | | | | |
| 8.2. There are serious accidents frequently happened on the shop floor | | | | | |
| 8.3. Basic safety precautions and training are given for unsafe conditions on the process. | | | | | |
| 8.4. There are caution signs and procedures to be followed everywhere on unsafe conditions in working areas | | | | | |
| 8.5. There is a counter measure to be installed to eliminate re-occurrence | | | | | |

## 1. Manufacturing Performance Dimensions

| **a. Cost (MP1)** | Strongly Agree (5) | Agree (4) | Neutral (3) | Dis-agree (2) | Strongly dis-agree (2) |
|---|---|---|---|---|---|
| 1.1. Using TPM methods, operating cost reduction is carried out. | | | | | |
| 1.2. There is an effort to cut back on overhead costs and energy consumption, for example. | | | | | |
| 1.3. A reduction in returns from customers because of flaws is | | | | | |
| 1.6. Cost analyses are used to estimate how much upkeep will cost | | | | | |
| 1.7. A preventative strategy needs to be put in place to stop incidents from happening again. | | | | | |
| **Quality (MP2)** | Strongly Agree (5) | Agree (4) | Neutral (3) | Dis-agree (2) | Strongly dis-agree (1) |
| 2.1. reduction of internal scrap and rework percentage in operations | | | | | |
| 2.2. improved client order compliance and specification compliance | | | | | |
| 2.3. Reduced customer returns because of faults | | | | | |
| 2.4. improved manufacturing standards and reduced process variation | | | | | |

| **Availability (MP3)** | Strongly Agree (5) | Agree (4) | Neutral (3) | Dis-agree (2) | Strongly dis-agree (1) |
|---|---|---|---|---|---|
| 1.1. Equipment Breakdowns are fixed in time for operation to | | | | | |
| 1.2. To reduce breakdowns, preventive measures have been | | | | | |
| 1.3. To prevent breaks down, machine operators inspect and maintain their equipment. | | | | | |
| 1.4. Causes of breakdowns(failure) are analyzed and counter measure | | | | | |
| 1.5. Technicians have enough resource to handle Equipment breakdowns to resume in time | | | | | |
| 1.6. There is enough number of skilled staff to conduct the maintenance sufficient in every shift | | | | | |
| 1.7. There is significant Equipment's unavailability time due to technical malfunctions. | | | | | |
| **Delivery (MP4)** | Strongly Agree (5) | Agree (4) | Neutral (3) | Dis-agree (2) | Strongly dis-agree (1) |
| 1.1. By having a high percentage of products delivered on time, the organization achieves reliable | | | | | |
| 1.2. The company achieving faster deliveries by averaging low lead times | | | | | |
| 1.3. There is preparedness to reduce cycle time to develop new product. | | | | | |
| 1.4. There is readiness to handle demand changes, like raw material preparation, before production | | | | | |

# Annex II: TPM Implementation Checklists

DUGDA CONSTRUCTION PLC
EQUIPMENT ADMINSTRATION & MAINTENANCE DEPARTMENT
RMC-2 (YOSEPH BATCHING PLANT)
ELKON-120 BATCHIN PLANT
DAILY MAINTENANCE CHECK LISTS

| No | Description | DAYS | Mon | Tue | Wed | Thu | Fri | Sat | Sun | Remark |
|---|---|---|---|---|---|---|---|---|---|---|
| No | Description | DATE | 04/17/23 – 04/22/23 | | | | | | | |
| | **Mixer** | 04/17/23 | | | | | | | | |
| 1 | Check inside of the mixer before starting operation. Keep the strange materials out of the mixer. | 04/22/23 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| 2 | Check oil level in hydraulic unit of mixer discharging gate. If necessary add oil. | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| 3 | Bolts of mixing paddle, scrapers, and arms must be tightening with 400Nm torque at the end of a working day. | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| 4 | Wash inside of the mixer and keep it clean from the concrete. | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| 5 | Check lever of discharging gate for manual operations. | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| 6 | Check the oil level of mixer gearbox. | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| 7 | Check automatic grease level if necessary add grease (OIL Type: Super grease EP-1 3.5 LT) | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| | **Cement weighing batcher** | | | | | | | | | |
| 1 | Clean the cement discharging area from hardened parts. | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| 2 | Check the connection elements and joints of load cell (joint end, pins, joint forks etc.) | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| 3 | Clean the load cells from dust. Keep clean them always. | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| 4 | Safety bolts should be loosening to avoid effects weighing operation. | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| 5 | Check load cells grounding properly or not fasten cable bolts. | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| 6 | Check cement weighing batcher output hoses. Clean them. | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| 7 | Release air from the cement batcher via ventilation hose. | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| | Water weighing batcher | | | | | | | | | |
| 1 | Clean load cells from dust. Keep clean them always. | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| 2 | Safety bolts should be loosening to avoid effect weighing operation | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| 3 | Check load cells earthling properly or not fasten cable bolts. | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | |

| | | DAYS | Mon | Tue | Wed | Thu | Fri | Sat | Sun | Remark |
|---|---|---|---|---|---|---|---|---|---|---|
| | Cement screw | | | | | | | | | |
| 1 | Grease screw bearings (Oil type: super grease EP-3) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| 2 | Check sealing of screw cover | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| | Cement silo | | | | | | | | | |
| 1 | Check the cement silo with eyes | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| 2 | Check the pneumatic installation | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| 3 | Check the butterfly valve manually at the bottom of cement silo | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | |

Additional information: Based on our inspection Should be progress on the mixer cleaning and greasing.

Prepared by: Milkiyas Dugasa

Sign.:

Date: April 21, 2022

Checked by: Cross Functional Team (Coordinator)

Sign.:

Date: April 22, 2022

Approved by: PEAD Manager

Sign.:

Date: April 22, 2022

Ready Mix Concrete
DUGDA
CONSTRUCTION PLC
Saris Plant

DUGDA CONSTRUCTION PLC
EQUIPMENT ADMINSTRATION & MAINTENANCE DEPARTMENT
RMC-2 (YOSEPH BATCHING PLANT)
ELKON-120 BATCHIN PLANT
WEEKLY MAINTENANCE CHECK LISTS

| No | Description | DATE | Remark |
|---|---|---|---|
| | **Mixer** | Feb 5, 2023 | |
| 1 | Grease hydraulic piston of discharging gates with grease gun. (Oil Type: super grease EP-2) | ✓ | |
| 2 | Grease mixer covers (Oil type: super grease EP-2) | ✓ | |
| 3 | Grease Cordon shaft with grease gun | ✓ | |
| 4 | Check mixing paddles and mixing arms, if necessary, renew them | ✓ | alread we measure the paddles and the liner |
| | **Cement weighing batcher** | | |
| 1 | Grease load cell hangers | ✓ | |
| 2 | Check the vibrator bolts and tighten them | ✓ | |
| 3 | Calibrate the batcher if its working incorrectly | ✓ | |
| | Water weighing batcher | | |
| 1 | Grease load cell hanger | ✓ | |
| 2 | Calibrate the batcher if its working incorrectly | ✓ | |
| | Additive weighing batchers | | |
| 1 | Check the pneumatic pistons work properly | ✓ | |
| 2 | Check the additive pump works properly | ✓ | |
| 3 | Calibrate the batcher if its working incorrectly | ✓ | |
| | Inline Silo | | |
| 1 | Aggregate discharging cover pin joint | ✓ | |
| 2 | Check aggregate bin cover bolts. Fasten them. | ✓ | |
| 3 | Check the vibrator bolts and tighten them. | ✓ | |
| | Weighing Conveyor | | |
| 1 | Calibrate the batcher if its working incorrectly | ✓ | |
| 2 | Lubricate conveyor drive, tightened drums bearings | ✓ | |
| 3 | Check tightened and drives drum bolts. Fasten them. | ✓ | |
| 4 | Grease load cell hangers | ✓ | |
| 5 | Check load cell bolts. Fasten them. | ✓ | |
| 6 | Check roller, scraper and seal bolts. Fasten them. | ✓ | |
| 7 | Check bolts of divider plate in waiting bin. | ✓ | |
| 8 | Check inner scraper if it is wear adjust it. | ✓ | |
| 9 | Please check the rollers whether they are turning or not the rollers assembly points shall be checked to make sure that there is no gravels, stones, etc. | ✓ | |

| No | Description | DATE | Remark |
|---|---|---|---|
| 10 | Check the interval V-shaped scraper of cleaning the tape, set the required distance. When worn out, replace with a new one. | ✓ | |
| | Skip Hoist | | |
| 1 | Grease rail | ✓ | |
| 2 | Grease aggregate bucket cover | ✓ | |
| 3 | Grease aggregate bucket drum bearings | ✓ | |
| 4 | Grease aggregate bucket steel wire cable | ✓ | |
| 5 | Grease aggregate bucket discharging cover bearing | ✓ | |
| 6 | Grease aggregate bucket steel wire cable connection pins | ✓ | |
| 7 | Grease aggregate bucket switch box bearings | ✓ | |
| | Cement silo | | |
| 1 | Check filter cartridge and clean it with pressure air | ✓ | |
| 2 | Check the solenoid valve and electronic flasher on the filter at the top of cement silo to avoid any danger | ✓ | |
| 3 | Clean air shocking system elements in the cement silo | ✓ | |

Additional information: The progress so far is good and accordingly the inspection and especially the cleaning being carried out on the mixer is encouraged

Prepared by: Milkiyas Dugasa

Sign.: ______

Date: Feb, 5, 2023

Checked by: Cross Functional Team (Coordinator)

Sign.: ______

Date: Feb 5, 2023

Approved by: PEAMD Manager

Sign.: ______

Date: Feb 5, 2023

Ready Mix Concrete
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**DUGDA CONSTRUCTION PLC**
**EQUIPMENT ADMINSTRATION & MAINTENANCE DEPARTMENT**
**RMC-2 (YOSEPH BATCHING PLANT)**
**ELKON-120 BATCHIN PLANT**
**MONTHLY MAINTENANCE CHECK LISTS**

| No | Description | DATE | Remark |
|---|---|---|---|
| | **Mixer** | March 1, 2022 | |
| 1 | Check if distance is 3mm between paddles and linings. If paddles or linings are weared renew them | ✓ | The paddles and the Lining clearance b/w is under specification |
| 2 | Check mixer gearboxes (High temperature, strange noise) | ✓ | It is normal tep. |
| 3 | Change and fasten all the bolts of lining shields of the mixer | ✓ | |
| 4 | Check filter cartridge and clean it with pressured air. | ✓ | |
| | **Cement silo** | | |
| 1 | Remove the filter cartridge to check and clean | | Removed and cleaned. |

Additional information: According to our recent inspection, we have found a positive change reduces pre-existing bearing wear. As we continue the monitorng in the same way, the plant down time of the previous six months has been reduced

Prepared by: Milkiyas Dugasa

Sign.:

Date: Mar, 1 2022

Checked by: Cross Functional Team (Coordinator)

Sign.:

Date: ~~Mar 1~~, 2022

Approved by: PEAMD Manager

Sign.:

Date: March 1, 2022

Ready Mix Concrete DUGDA CONSTRUCTION PLC Saris Plant

DUGDA CONSTRUCTION PLC

**DUGDA CONSTRUCTION PLC**
**EQUIPMENT ADMINSTRATION & MAINTENANCE DEPARTMENT**
**RMC-2 (YOSEPH BATCHING PLANT)**
**ELKON-120 BATCHIN PLANT**
**SIX MONTHLY MAINTENANCE CHECK LISTS**

| No | Description | DATE | Remark |
|---|---|---|---|
| | **Mixer** | Sep 3, 2022 | |
| 1 | Refill mixer gearbox oil after the first 100 working hours and then do it in every six months (OIL TYPE: MINERAL ISO VG 320 30 LT) | ✓ | |
| | Skip Hoist | | |
| 1 | Renew aggregate bucket steel wire cable | ✓ | Changed. |
| 2 | Renew aggregate bucket gearbox oil. (OIL TYPE: MINERALS ISO VG 220 37 LT) | ✓ | Changed |
| | Cement Screw | | |
| 1 | Renew screw gearbox oil. (OIL TYPE: MINERAL ISO VG 320 1.5 LT) | ✓ | Changed screw gearbox oil |
| 2 | Renew screw bearing | ✓ | Changed Screw conveyor, Leaking |

Additional information: Based On the Results of our inspection today, Sement Screw conveyor bearing should be Replaced next week, in addition the screw gear box has a leak, So that leak must be Removed during the weekly inspection.

Prepared by: Milkiyas Dugasa

Sign.: ____

Date: Sep, 3 2022

Checked by: Cross Functional Team (Coordinator)

Sign.: ____

Date: Sep 3, 2022

Approved by: PEAMD Manager

Sign.: ____

Date: Sep 3, 2022

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