

Improving plant availability through Effective Maintenance System: A Case Study in MESSEBO CEMENT FACTORY



**Ethiopian Institute of Technology-Mekelle
School of Mechanical and Industrial Engineering**

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the requirements for a Master of Science in Industrial Engineering
(Production and Industrial System Engineering)**

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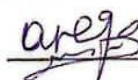
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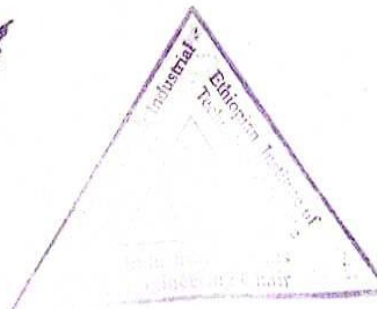


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Declaration

- I hereby declare that the thesis titled Improving plant availability through Effective Maintenance System : a Case Study In MESSEBO CEMENT FACTORY the research, analysis, and findings presented in this thesis are the result of my own efforts, except where due references have been made to the work of others.
- I affirm that this thesis has not been previously submitted to any other institution or university for the award of any degree or diploma. The information and data presented in this thesis have been obtained through reasonable and ethical means, and I have accordingly acknowledged all sources of information, including published literature, personal communications, and online resources.
- I understand that any unethical practices, such as plagiarism, fabrication of data, or misrepresentation of information, will be considered a serious offense and may result in the rejection of this thesis or disciplinary action by the university.
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Certification

This is to certify that the research paper titled " Improving plant availability through Effective Maintenance System : a Case Study In MESSEBO CEMENT FACTORY " prepared by Araya Tesfahun, a student in the Department of Industrial Engineering at Mekelle University, is an original work completed under my supervision.

I have reviewed the paper and am satisfied that it meets the academic standards required for the partial fulfillment of the degree of Master of Production and System Engineering. The findings and recommendations presented in this paper have the potential to contribute to the improvement of availability and OEE of messebo cement factory.

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Abstract

Corrective maintenance technique is have long been one of an obstacle to Messebo cement factory's efforts to maintain high plant availability. In the fiscal year 2023/24 MESSEBO cement factory is experiencing suboptimal operational efficiency due to the persistently low availability of critical machinery across its production lines. Key equipment essential for raw mill processing, clinker production, cement milling, and packaging is operating below industry- standard availability benchmarks (85-90%), leading to reduced production capacity, increased downtime costs, and potential delays in meeting customer demand.

This research examines the existing maintenance system on plant availability and over all equipment effectiveness (OEE) in the context of messebo cement factory. The study's main objectives were to assess current maintenance procedures, pinpoint the underlying reasons for outages, and suggest workable plans to improve operational effectiveness through manpower development, predictive technology, and infrastructure improvements.

The research used mixed- methods quantitative and qualitative approach, through a comprehensive case stud approach analyze maintenance data in terms of performance metrics and downtime cases. The research findings highlighted several critical issues. A reactive maintenance culture prevailed, with over 56% of respondents indicating that preventive tasks were often skipped during peak production periods. Aging infrastructure and unstable power supply led to more than 30 major equipment failures annually. Furthermore, outdated manual record keeping practices undermined data accuracy, despite 83% participants acknowledging the link between downtime and the absence of predictive maintenance. Despite these challenges, the study identified several opportunities for improvement. Notably, 60% of the workforce expressed support for modernization efforts, while 50% believed that real-time monitoring systems could significantly enhance decision making and efficiency. The research recommended immediate piloting of IOT sensors on critical equipment (e.g, cement mill rollers), enforcing strict PM via digital checklists. Medium term strategies include CMMS implementation for centralized planning and predictive analytics, alongside specialized maintenance team training. Long term goals target transitioning to predictive maintenance (aiming for 20-40% downtime reduction), fostering cross departmental collaboration through shared KPIs, and securing leadership support by demonstrating ROI.

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Chapter one: Introduction

1.1 Background of the study

Effective maintenance systems are a cornerstone of industrial efficiency, particularly in sectors where continuous and high production capacities are critical. Cement production, a cornerstone of infrastructure and development, heavily relies on the availability of complex machinery and equipment. Ensuring consistent machine availability is essential for meeting production targets, maintaining product quality, and sustaining operational profitability. This challenge becomes even more pressing in large-scale operations such as MESSEBO cement factory, one of Ethiopia's largest and most prominent cement producers.

MESSEBO cement factory, with over 20 years of experience, has become a key player in Ethiopia's industrial landscape. With a daily production capacity of 7000 tons and annual capacity of 2,100,000 tons achieved within 300 operational days, the factory plays a pivotal role in supporting the country's developmental goals. Despite its significant contributions, the factory faces substantial challenges related to machine and plant availability. In the fiscal year 2023/24 MESSEBO cement factory is experiencing suboptimal operational efficiency due to the persistently low availability of critical machinery across its production lines. Key equipment essential for raw mill processing, clinker production, cement milling, and packaging is operating below industry- standard availability benchmarks (85-90%), leading to reduced production capacity, increased downtime costs, and potential delays in meeting customer demand.

MESSEBO cement factory, has relied on conventional maintenance practices. While these methods address immediate repair needs, they often fail to mitigate underlying causes of machine breakdown. Reactive maintenance approaches result in unplanned downtimes, increased repair costs, and reduced equipment lifespans. To overcome these challenges, the adoption of modern maintenance system becomes essential.

Modern maintenance systems, such as predictive and condition-based maintenance, leverage advanced technologies, sensors, and data analytics, to monitor equipment health and predict failures before they occur. By transitioning to such systems, MESSEBO cement factory can reduce unplanned downtimes, optimize resource utilization, and enhance overall machine availability. This would not only minimize production losses but also improve operational efficiency and cost-effectiveness.

This study focuses on the potential of modern maintenance systems to improve plant availability at MESSEBO cement factory. By examining existing maintenance practices, evaluating modern methodologies, and addressing the challenges of implementation, the research aims to provide actionable insights. The study seeks to highlight the importance of transitioning to a proactive maintenance framework, ensuring sustainable growth and strengthening messebo cement factory's role in Ethiopia's industrial development.

1.2 Problem statement

In the fiscal year 2023/24 MESSEBO cement factory is experiencing suboptimal operational efficiency due to the persistently low availability of critical machinery across its production lines. Key equipment essential for raw mill processing, clinker production, cement milling, and packaging is operating below industry- standard availability benchmarks (85-90%), leading to reduced production capacity, increased downtime costs, and potential delays in meeting customer demand.

Table 0-1 Affected machines and current availability rates [1]

Line	Machine	Availability
2	Limestone Crusher	67.5%
1	Raw mill	79.8%
2	Raw mill	66%
2	Kiln	67%
1	Kiln	74.45%
1	Cement mill	60%
1	Packing	79%
2	Packing	79%

Impact on operations

1. Production Losses; frequent breakdowns and prolonged downtime hinder the factory's ability to meet daily production targets.
2. Increased Costs; unplanned maintenance, emergency repairs, and idle labor increase operational cost.
3. Supply chain disruptions; delays in processing and packaging risk order fulfillment timelines, affecting customer satisfaction.
4. Resource inefficiency; underutilization of installed capacity reduces return on investment for high-cost machinery.

1.3 objective

1.3.1 General objective

To improve plant availability at MESSEBO cement factory by implementing an effective maintenance system, thereby reducing production losses and enhancing operational efficiency.

1.3.2 Specific objective of the study

- To assess the existing maintenance practice and their impact on machine availability and at Messebo cement factory.
- To identify the root causes of machine downtime and production losses in the factory.
- To develop actionable recommendations for transitioning from traditional to modern maintenance systems to ensure sustained plant and machine reliability.

1.4 significance of the study

This study explores the adoption of effective and modern maintenance systems as a pathway to transforming messebo cement factory's operation by improving plant and machine availability, which will enhance operational efficiency, help meet production targets, and minimize financial losses, ensuring the factory's long term sustainability. The recommendations from the study aim to introduce advanced practices that can revolutionize how the factory manages machine health, offering real time insights, that and minimize unplanned down times.in addition to financial benefits, the study emphasizes the importance of skill development within the workforce, as transitioning to modern systems will require training and capacity building, equipping employees with the necessary expertise to manage new technologies. Ultimately, the findings of this research hold far reaching implications by reducing production interruptions, strengthening messebo's market position, and adoption of modern maintenance practices supports sustainable production, ensuring messebo's operations are both efficient and environmental responsible, marking a crucial step toward operational excellence, economic growth, and sustainable industrial development.

1.5 Scope of the study

This study focuses on improving plant availability at messebo cement factory through the implementation of effective maintenance systems. The scope is primarily limited to evaluating the current maintenance practices at the factory, identifying the challenges related to equipment downtime, and assessing the potential benefits of adopting modern maintenance systems such as predictive maintenance, condition based maintenance, and real time monitoring technologies.

The study will examine messebo cement factory's maintenance activities within its production facilities, specifically targeting key machinery such as kilns, crushers, mills, and conveyors, which are critical to the factory's daily operations. It will analyze the financial impact of unplanned downtimes and the root causes of inefficiencies in the current system, focusing on the direct relationship between maintenance strategies and machine availability.

Furthermore, the scope includes an exploration of modern technologies that be integrated into messebo's existing maintenance framework, data analytics, vibration analysis, and thermal imaging.

The research will not extend to other factories or industries outside messebo cement factory, although the findings may have broader implications for similar manufacturing. The scope also does not include the financial analysis of the complete overhaul of all equipment but focuses primarily on improving maintenance practices for enhanced plant and machine availability. The time frame of the study is limited to the factory's operations during the 2023/24 fiscal year, with an emphasis on understanding the current state of maintenance and proposing feasible improvements.

In conclusion, the scope of this study is confined to evaluating and proposing modern maintenance systems at messebo cement factory, aiming to improve equipment availability, reduce downtime, and enhance overall operational efficiency within the factory's production environment.

1.6 Limitations

Because different facilities have different operational settings that affect production realities, such as raw material quality, equipment age, or regional climate, the study's relevance may vary even if it provides insights into optimizing maintenance methods for cement plants. Additionally, the integrity and completeness of previous maintenance data which may be inconsistent in plants with disjointed record-keeping systems are critical to the validity of recommendations. Beyond technical constraints, obstacles such as the high initial costs of contemporary tools or suggested tactics, highlighting the disconnect between theoretical fixes and real-world implementation difficulties in environments with limited resources.

1.7 organization of the thesis

The study will be organized in the five chapters,

1. First chapter; an introduction part, gives the background of the study and discusses best maintenance practices, contains a brief discussion of research objectives, and scope of work.
2. Chapter two; a literature review that covers various topics relevant to Improving plant availability through Effective Maintenance System: a Case Study in MESSEBO CEMENT FACTORY
3. Chapter three; a detailed overview of the methodology for the study, to include data collection, data analysis.
4. Chapter four; data analysis and interpretations also present results and discussions.
5. Chapter five; contains discussion of the results, conclusion derived and recommendations.

Chapter two: literature reviews

Introduction

Improving plant availability, as well as overall equipment effectiveness (OEE), is crucial for enhancing productivity and operational efficiency in manufacturing. OEE serves as a comprehensive metric reflecting equipment availability, performance efficiency, and quality rate. Modern maintenance systems, such as total productive maintenance (TPM) and preventive maintenance, play a significant role in achieving these goals. This literature review explores about maintenance, maintenance strategies, and maintenance performance metrics key components of OEE, technological enablers, challenges in implementation, and an analysis of related studies.

2.1 Maintenance

Maintenance is a profession to keeping the factory running in the shape, making equipment reliable, productive, and secure to operate. According the researchers maintenance function has historically been thought of as a critical cost of doing business. However, advanced technologies and innovative practices have positioned the maintenance function as an integral part of the overall profitability business [2]. Advanced maintenance techniques and practical approaches have the potential to significantly enhance competitive advantages in the international market competitions. Just as the finely meshed gears of machinery must work together for the machine to perform its function, production, safety, design engineering, and other members including maintenance work together to achieve true excellence. The challenge for today's maintenance managers, reliability professionals, and all those involved in the maintenance profession is to capture these opportunities. This requires establishing standards for maintenance and reliability practices, creating an appropriate information system to collect facts and build enthusiasm, and initiating enabling action plans. The responsibility of keeping our equipment and facility in optimal working condition is not just that of a small group of engineers and technicians but of every individual in the entire organization [3]. We all benefit from this optimal condition, and therefore we all should be empowered to learn and intervene more in the vital process of preservation. TPM (Total productive Maintenance) is exactly the discipline that will allow us to achieve such an optimal level of success [4].

2.2 Maintenance strategies

Maintenance strategies are the approaches or methods used to ensure that equipment and machinery in an industrial facility operate reliably and efficiently. These strategies are designed to prevent or reduce downtime, extend the life span of equipment, and optimize performance. The goal is to minimize the costs of maintenance while maximizing machine availability and production efficiency [5]. There are several maintenance strategies, each suited to different types of equipment and operational needs. The main strategies include;

2.2.1 Breakdown maintenance

As the historical data indicated that maintenance is one of the first maintenance programs being implemented in the industry [6]. The approach to maintenance is totally corrective maintenance

and only act when the equipment needs to be fixed means after failure. This maintenance strategy has no monotonous maintenance task and also defined as no scheduled maintenance strategy means there is not practice preventive maintenance. To correct the problem, correct maintenance performed onto the equipment rather than preventive. Thus, maintenance activities may include of repairing, restoration or replacement of components. The strategy is to apply the corrective maintenance activity only, which is required to correct a failure that has happened or is in the process of stirring [7].

2.2.2 Preventive maintenance

This is time based preventive maintenance strategy where on a prearranged basis, equipment is taken off-lined opened up and inspected. Based on visual inspection, repairs are conducted and the equipment is the put back on-line [8]. Thus under this equipment maintenance program or strategy, replacing, overhauling or remanufacturing an item is conducted at a fixed intervals regardless of its condition at the time. As most researchers finding although this is well intended strategy, the process can be very expensive as typically 95% of time everything was alright. However, some preventive maintenance is crucial as some regulation such as regulation required that annual/bi-annual inspection to be conducted [9].

2.2.3 Predictive maintenance

Predictive maintenance strategy is condition based approach maintenance. The approach is based on determining of the equipment condition in order to evaluate whether equipment will fail during some future period, and then taken to evade the consequences of those failures. This is where predictive technologies vibration analysis, infrared thermographs, ultrasonic detection are utilized to determine the condition of equipment, and to decide on any necessary repairs [10]. Apart from the predictive technology, statically process control techniques, equipment performance monitoring or human senses are also adapted to monitor the equipment condition. This method is more economically feasible strategy as labors, materials and production schedules are used much effectively.

2.2.4 Proactive maintenance

Dissimilar the three types of maintenance strategies which have been deliberated earlier, proactive maintenance can be considered as another advanced approach to maintenance strategy. Unlike to prevent maintenance that based on time intervals or predictive maintenance that based on condition monitoring, proactive maintenance focused on the monitoring and correction of root causes to equipment failures. The proactive maintenance program is also designed to extend the useful timespan of the equipment to reach the wear-out stage by adaption a high mastery level of operating precision.

2.3 Total Productive maintenance

Total productive maintenance is a holistic approach that integrates maintenance into daily operations, emphasizing proactive and preventive techniques. Implementing TPM has been shown to significantly improve OEE by minimizing breakdowns and enhancing performance and quality

rates. TPM represent for Total productive maintenance and function builds a close relationship between maintenance and productivity, showing how good care and keep of the equipment will result in a higher productivity. TPM is not only a strategy, but also a new philosophy of continuous improvement and team work that creates a sense of ownership in the operator(s) of each machine as well as in their supervisor and the maintenance people involved. All participants assume a real commitment. We all reach advanced attitude of higher responsible. Production supervisors, operators, superintendents want to have a very clear idea about total productive maintenance [11].

2.3.1 Goals Total Productive Maintenance

The goal of Total Productive Maintenance focuses on enhancing corporate culture through advance of human resources and plant equipment. The Japanese institutes of plant maintenance has put forward the five goals of Total Productive Maintenance which are the reduce requirements for the Total Productive Maintenance development [14].

1. Improving equipment effectiveness.
2. Improving maintenance efficiency and effectiveness.
3. Early equipment management and maintenance prevention.
4. Training to improve skills of all people involved.
5. Involving operators in routine maintenance.

2.3.2 Pillars Total Productive Maintenance

The japan institute of plant maintenance proposes the introduction of total productive maintenance program is based on the implementation of a series 8 pillars of Total Productive Maintenance in a systematic way to optimize plant and equipment efficiency by creating perfect relationship between man and equipment.

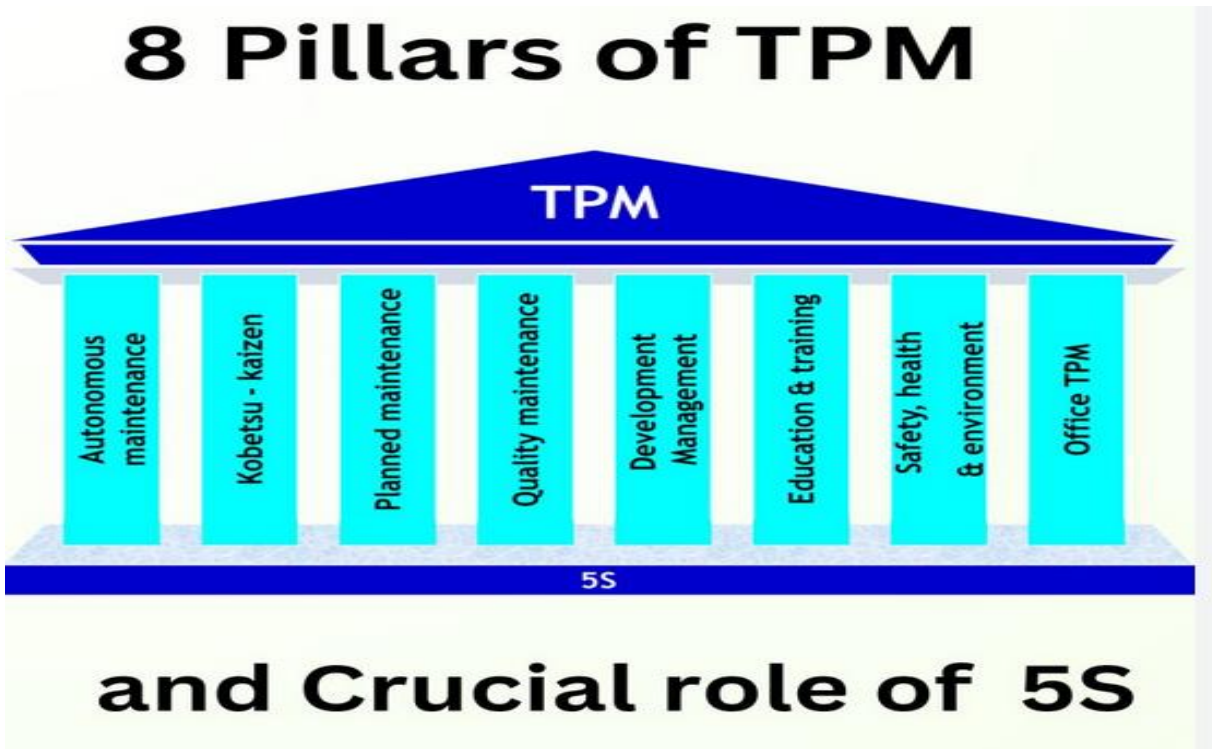


Figure 1 representation of common structure of TPM

Structure of TPM [11]

1. 5'S

The five “S” (5S) practice is a preparatory phase of total productive maintenance which is a technique used to establish and maintain quality environment in an organization or industries. According to many researchers a well- organized workplace motivates people, both on the shop floor as well as others. 5’S advances safety, work efficiency, improves productivity and establishes a sense of ownership, the 5’S is developed in japan for work place organization and housekeeping and represents for Japanese words: seiri, seiton, seiso, seiketsu and shitsuke which connote organization, tidiness, cleaning, standardization and discipline respectively [16]

Seiri: - sort out: this is to remove what is not requires and to keep what is needed in the nearby and items that are not needed in the near future in the appropriate way so that items can easily be accessible [17].

Seiton: - Organizing: To organize and place items in a reachable way to reduce search time. The concept is that a place for everything and everything in its right place. Items are marked to identify easily [18].

Seiso:- Cleaning: Every employee participate and responsible for cleaning work place around them. Things kept clean and polished; no trash or dirt and no leakage in the workplace. Cleaning working area create feeling of freshness and vividness [17].

Seiketsu:- standardization: Developing standards for cleaning the work place for whole organization to keep neat and clean. It encompasses both personal cleanliness and the cleanliness of the environment. It is implemented after the above 3's principles practiced well in the organization to maintain the practice [17].

Shitsuke:- Self-discipline: the main principle of shitsuke is to repeatedly practice the above 4's so that they become habit to every employee. This activity helps the employee to adhere to the standards and rule. Once fully implemented, the 5'S process can increase morale, create positive impressions on customers, and increase efficiency and organization. Employees will feel better about where they work and transforms the physical environment of the work area which makes the organization more profitable and competitive in the market place [19]

2. Autonomous Maintenance (Jishu Hozen)

Autonomous Maintenance allows operators to take ownership of basic maintenance tasks or activities like cleaning, inspection, lubrication, and minor adjustments. This approach increases operator awareness of machine conditions and assistances in early detection of abnormalities [20].

3. Kobetsu Kaizen

Also according the researchers this pillar involves continuous efforts to identify and eliminate losses or inefficiencies in equipment, processes, and operations. Kaizen teams work collaboratively to target specific problems and implement sustainable solutions minimize waste [21].

4. Planned Maintenance

According the researchers planned maintenance focuses on scheduling proactive and preventive maintenance tasks based on time or usage or before failure the maintenance equipment. It reduces unplanned downtime and ensures optional equipment performance by eliminate potential issues before they occur [21].

5. Standardization of maintenance Activities

Also standardization of maintenance activities focuses on creating and following similar procedures for maintenance tasks. It objective is to eliminate variations, ensure consistent quality, and promote adherence to best practices. By standardizing activities, it improve reliability, efficiency, and safety [22]

6. Quality Maintenance

As the researchers said quality maintenance ensures that machines and processes consistently produce defect-free products. It includes maintaining equipment to meet quality standards and removing root causes of defects through proactive measures [23]

7. Training

According to the researchers the pillar underlines developing the skills and knowledge of operators, maintenance personnel, and managers to foster a competent workforce. Continuous training ensures that everyone can effectively contribute to total productive maintenance initiatives [24]

8. Office TPM

Also administrative total productive maintenance applies to administrative functions to eliminate waste, improve workflows, and enhance efficiency in office processes, ensuring alignment with overall production objective [25].

9. Safety, Health and Environment

According to the writers the pillar prioritizes creating a safe and environmentally friendly workplace by identifying and mitigating risks. It integrates safety measures into daily activities and fosters a culture of health and environmental awareness [26]

2.4 Elements of Effective Maintenance Management

There are many elements of effective maintenance management whose effectiveness is the key to the overall success of the maintenance activity. Many of these elements are described below.

2.4.1 Maintenance policy

According to researchers a maintenance policy is one of the most useful elements of effective maintenance management. It is necessary for continuity of operations and a pure understanding of the maintenance management program, nevertheless of the size of a maintenance organization. Regularly, maintenance organizations have manuals containing items such as policies, programs, goals, responsibilities and authorities for all levels of supervision, reporting requirements, useful methods and techniques, and performance measurement guides. Lacking such documentation, a policy manual, a policy document must be developed containing all essential policy data [27]

2.4.2 Material Control

According to the researcher finding indicated that past experience indicates that, on average, material costs account for approximately 30% to 40% of total direct maintenance costs. Effective utilization of personnel depends largely on effectiveness in material coordination. Material problems can lead easily to false starts, excess travel time, delays, unmet due dates, etc. steps such as job planning, coordinating with purchasing, coordinating with stores, coordination of issuance

of materials, and reviewing the completed job can help minimize material- related problems. Decisive whether to keep spares in storage is one of the most important problems of material control [27]

2.4.3 Work Order System

As the researchers definition a work order allows and directs an individual or group to perform a given mission. Also a well-defined work order system should cover all the maintenance jobs required and skillful, whether repetitive or one time jobs. The work order system is convenient to the researchers even though the type and size of the work order can vary from one maintenance organization to another, a work order should at least contain information such as requested and planned completion dates, work description and its causes, planned start date, labor and material costs, item or items to be affected, work category preventive maintenance, repair, installation, etc., and suitable approval signature [28]

2.4.4 Equipment Records

According to the researchers Equipment Records play a vital role in effectiveness and efficiency of the maintenance organization. Usually, equipment records are classified in to four calcifications: maintenance work performed, maintenance costs, inventory, and files. The maintenance work performed classification contains chronological documentation of all repairs and preventive maintenance performed during the item's life span to date. The maintenance cost category contains historical data accumulations of labor and material costs by items. Regularly, information on inventory is provided by the stores or accounting department. The inventory category includes information such as property number, size and type, procurement cost; date manufactured or assimilated manufacturer, and location of the equipment/item. The files category includes operating and service manuals, warranties, drawings, and so on. Equipment records are necessary when procuring new items/equipment to define operating performance trends, troubleshooting breakdowns, making replacement or adjustment decisions, investigating incidents, identifying areas of concern, performing dependability and maintainability studies, and conducting life span cost design studies [29]

2.4.5 Job Planning and Scheduling

Also according to the researchers job planning is a crucial element of the effective maintenance management. A number of responsibilities may have to be performed preceding to commencement of a maintenance job; for example finding of parts, tools, and materials, coordination and delivery of parts, tools, and materials, proof of identity of methods and sequencing, coordination with other departments, and securing safety authorizations. Even though the degree of planning required may vary with the craft involved and methods used, past experience shows that on average one planner is mandatory for every twenty crafts persons. Strictly speaking, formal planning should cover 100% of the maintenance workload but emergency jobs and small, straightforward work assignments are performed in a less formal environment. Thus, in most maintenance organizations 80% to 85% planning coverage is attainable. Maintenance scheduling is as significant as job planning. Schedule usefulness is based on the availability of the planning function. For large jobs,

in particular those needful multi-craft coordination, serious consideration must be given to using methods such as program evaluation and review technique (PERT) and critical path method (CPM) to swear effective overall control [30].

2.4.6 Backlog Control and Priority System

The quantity of backlog within maintenance organization is one of the decisive factors of maintenance management effectiveness. Proof of identity of backlogs is significant to balance manpower and workload necessities. Additionally, decisions concerning overtime, hiring, subcontracting, shop assignments, etc., are largely based on backlog data. Management makes use of various catalogues to make backlog related decisions. The determination of job precedence in maintenance organization is essential since it is not possible to start every job the day it is requested. In assigning job priorities, it is significant to consider factors such as importance of the item or system, the type of maintenance, mandatory due dates, and the length of time the job awaiting scheduling will take [27]

2.4.7 Performance Management

Fruitful maintenance organizations regularly measure their performance through numerous means. Performance analyses contribute to maintenance department efficiency and are indispensable to enlightening the downtime of equipment, peculiarities in operational behavior of the concerned organization, developing plans for future maintenance, and so on [27]

2.5 Literature Summary

S.N	Issue	Author	Methods	Variables	Findings
1	An evaluation of preventive maintenance framework in an Italian manufacturing company	Kundu, Kaustav and Cifone, Fabiana and Costa, Federica and Portioli-Staudacher, Alberto and Rossini, Matteo [31].	Conceptual framework of preventive maintenance	World class manufacturing (WCM)- based tools	A small- medium manufacturing business effectively implemented a preventive maintenance strategy, creating a culture of corrective maintenance and employee satisfaction

2	Maintenance strategy in Malaysian manufacturing companies: a total productive maintenance (TPM) approach	Mad Lazim, Halim and Ramayah, T [32].	The correlations among TPM practices were also evaluated accordingly	TPM may improve collaboration b/n an organization's maintenance and other activities, acting as an aggressive strategy for competitive contexts that demand zero breakdowns, stoppages, or equipment failures.	The correlation research shows a positive and substantial association between TPM activities such as autonomous maintenance, scheduled maintenance, and TPM strategy in Malaysian manufacturing business
3	Plant Maintenance Modeling through availability analysis in raw mill of cement production	N.Jufri, N.Siswanto Dec.29 2020 [33].	Discrete system simulation to evaluate raw mill machine availability and calendar days.	System availability (72.83%) Calendar days (239), TTF, TTR, overhaul duration.	Best scenario (preventive maintenance increased availability to 83.04% and calendar days to 255 by optimizing TTF, TTR, and overhaul time.
4	Modeling and Availability Analysis of cement manufacturing plant subject to coverage factor and human failure	R. Sudhir, Vineeta Oct 15, 2020 [34].	Markovian birth death model with (R-K) Method for solving differential equations	Coverage factor, human failure, repair availability, series subsystems, exponential distributions.	The model successfully quantified the impact of coverage factor and human failure on the overall availability of the cement plant

5	Changing the focus from corrective maintenance to preventive maintenance of the technical workforce to achieve an improvement of the performance of total maintenance activities of Brasco in Pointe-Noire	Bierman, Jan-Willem [35].	Scenario, several methods are used for improvements in production, such as value stream mapping, kaizen, just in time, kanban, and TPM, etc.	Produce an agile system to sustain improvements in productivity through a methodology coupled with value stream mapping in industry 4.0. value stream mapping is a lean based method and is used for the maximization of productivity by the elimination of non-value added activities	Strongly believe that proposed methodology is able to provide a robust guideline to management teams involved in decision making and it is applicable to all types of shop floor management, including industry 4.0.
6	Reliability availability and maintainability analysis of a cement plant	Choudary devendra and Tripathi, Mayank and Shankar, Ravi [36]	Collected two years of TBF and TTR data from a cement plant's critical subsystems, tested data independence via trend/serial correlation analysis, fitted distributions using easy fit and evaluated preventive maintenance effectiveness through system simulations.	TBF, TTR, subsystem reliability/availability, maintenance/management-related underutilization.	Raw/coal mills critical for reliability; kiln critical for availability; reducing mill repair time improves availability; 17% underutilization (maintenance) 15% (management)

Table 0-1 literature summary

2.5.1 Research Gap

Existing studies on maintenance strategies exhibit recurring gaps, including limited exploration of predictive technologies (IOT, machine learning) for real time failure prediction, insufficient integration of socio technical factors (e.g., workforce training, organizational culture) with technical subsystems, and overreliance on single case or context specific analysis, hindering generalizability. Many lack cost benefit frameworks to quantify economic tradeoffs between preventive maintenance costs and efficiencies gains, while others overlook dynamic external factors (e.g., supply chain disruptions) and nontraditional configurations (e.g., parallel

setups), validation through empirical, real world data longitudinal assessments remains sparse, limiting practical scalability. Additionally, holistic strategies balancing human error, management inefficiencies, and advanced maintenance models (beyond exponential distributions or perfect repairs) are underexplored, necessitating interdisciplinary, adaptable frameworks for diverse industrial contexts.

CHAPTER THREE: METHODOLOGY

3.1 Research Design

This study adopts a mixed-methods approach, integrating both qualitative and quantitative research techniques to comprehensively analyze the impact of modern maintenance systems on plant availability in messebo cement factory. The research will employ case study methodology to provide an in-depth understanding of the existing maintenance practices and the potential for modernization.

3.1.1 Justification for the chosen research design

The research study titled *“improving plant availability through Effective maintenance systems: A case study in messebo cement factory”* employs a mixed- method research design, incorporate both qualitative and quantitative approaches. This research design is chosen based on the following factors:

Alignment with research objectives: the research aims to assess existing maintenance practices, identify root causes of downtime, explore modern maintenance systems, and evaluate the feasibility of advanced maintenance technologies. A mixed-method approach enables a comprehensive understanding of both numerical data (Quantitative) and in depth insights (Qualitative) from maintenance and stakeholders.

3.2 Population and sampling

3.2.1 Target population

The target population is the entire population, or group, that a researcher is interested in researching and analyzing. A sampling frame is then drawn from this target population. The target population includes maintenance engineers, plant operators, production managers, and technical staff involved in machine maintenance at the cement factory. Additionally, maintenance logs and historical performance data form part of the population under study.

3.2.2 Sampling Method

Purposive sampling, also known as judgmental or selective sampling, is a non-probability sampling technique where the researcher selects participants based on specific characteristics, qualities, or criteria that are relevant to the research question. This method is often used when the researcher seeks to gather in-depth information from a targeted group that is particularly knowledgeable or experience in the area of study [37].

The sampling method described involves a non-random selection process where participants are intentionally chosen based on the researcher’s expertise and judgment, prioritizing a targeted approach to focus on individuals or groups that align with specific criteria relevant to the study’s objectives. This strategy is commonly employed in qualitative research, where the goal is to gather rich, detailed insights rather than generalize the findings to broader populations. It emphasizes flexibility, allowing researcher to adapt their sampling strategy as the study evolves, such as

refining criteria or exploring emerging themes, ensuring alignment with the research's exploratory and context-sensitive nature.

A purposive sampling method will be used to select participants who have direct experience and knowledge of maintenance practices and challenges in the cement factory. This method is appropriate because it allows me to focus on individuals who can provide the most relevant and insightful information for the study.

3.2.3 Sample size determination

The sample size will be determined based on data saturation, where participants are selected until no new information or themes emerge from the data. Approximately 30 key informants will be selected, including;

- i. Maintenance managers and engineers (13 participants)
- ii. Technicians and operators (12 participants)
- iii. Production managers and decision-makers (5 participants)

3.3 Research approach

A case study approach will be employed, focusing on a single cement factory as the unit of analysis. This approach is suitable for obtaining detailed insights into maintenance practices, equipment performance, and the effectiveness of modern maintenance techniques.

According to researchers a case study is in-depth, detailed examination of a particular case (or cases) within a real-world context [38]

3.3.1 Data Collection Methods

Data collection or data gathering is the process of gathering and measuring information on targeted variables in an established system, which then enables one to answer relevant questions and evaluate outcomes. Data collection is a research component in all study fields, including physical and social sciences, humanities, [39] and business. While methods vary by discipline, the emphasis on ensuring accurate and honest collection remains the same. The goal for all data collection is to capture evidence that allows data analysis to lead to the formulation of credible answers to the questions that have been posed.

The study will use multiple data sources to ensure reliability and validity:

i. Primary Data Collection

Primary data is a data that is collected for usage in specific study. Gathering primary data is important in order to create an understanding of specific research object [40]. The primary data for this study has been collected through observations, interviews and questionnaires.

- i. Interviews: semi-structured interviews will be conducted with maintenance engineers, plant managers, and operational staff to understand current maintenance practices, challenges, and perceptions of modern maintenance systems.
- ii. Surveys and questionnaires: structured surveys will be distributed to employees involved in maintenance and production to gather quantitative data on machine downtime, failure rates, and maintenance effectiveness.
- iii. Direct Observations; on site observations will be conducted to assess the physical condition of equipment, maintenance execution, and adherence to existing maintenance plans.

Observations were as a way to establish how the maintenance work was conducted at MCF. The observations were used to get an understanding how maintenance were performed at the company and the behavior of the people involved.

A visit to the MCF begins with a visual survey of the equipment and facilities. Observing the physical condition of key machinery, such as kilns, crushers, mills, and conveyors, can indicate whether they are well-maintained or show signs of wear and tear. For instance, rust, oil leaks, or excessive vibration can hint at neglected maintenance practices or poor monitoring.

- iv. The work flow of maintenance activities has been observed by shadowing technicians during scheduled tasks. How preventive or corrective maintenance is performed, including adherence to safety protocols, the use of proper tools, and the application of technical knowledge. Delays in obtaining spare parts, unclear instructions, or excessive time spent troubleshooting may reveal underlying issues in planning or resource allocation.

2. Secondary Data Collection

- i. Maintenance Logs and Reports: historical maintenance records, breakdown reports, and downtime logs will be analyzed to identify trends and patterns.
- ii. Production Data: data related to machine performance, and production losses due to maintenance issues will be collected.

3.4 Data Analysis Methods

3.4.1 Qualitative Data Analysis

Qualitative data analysis (QDA) is the process of systematically examining non – numerical data (such as text, audio, video, or images) to identify patterns, themes, meanings, and insights. Unlike quantitative analysis, which focuses no numerical data and statistical methods, qualitative analysis emphasizes understanding the context, perspectives, and experiences of participants. It is commonly used in social sciences, humanities, and other fields where exploring complex phenomena is essential [37]

Root Cause Analysis (RCA): Techniques such as the fishbone diagram (Ishikawa) will be applied to diagnose the primary causes of machine downtime and production losses.

Root Cause Analysis (RCA) is a systematic process used to identify the understanding causes of problems, incidents, or failures. The goal of RCA is to determine what happened, why it happened,

and how to prevent it from happening again. It is widely used in fields such as engineering, healthcare, manufacturing, and business to improve processes, enhance safety, and reduce risks.

Key principles of RCA:

1. **Focus on Root Causes:** RCA aims to identify the fundamental reasons for a problem, rather than just addressing symptoms.
2. **Systematic Approach:** It involves structured methods and tools to analyze data and trace the problem to its origin.
3. **Prevention- Oriented:** The ultimate goal is to implement solutions that prevent recurrence of the issue.
4. **Collaborative Effort:** RCA often involves a team of stakeholders with diverse expertise to ensure a comprehensive analysis.

RCA Tools that are used for the research is as follows

According to the researcher's fishbone diagram, also known as the Ishikawa diagram or cause and effect diagram, is a visual tool used to systematically identify and organize the potential causes of a specific problem or effect. It was developed by Dr. Kaoru Ishikawa, a Japanese quality control expert, in the 1960s. The diagram resembles the skeleton of a fish, with the "Head" representing the problem and the "bones" representing categories of causes [42]

Purpose:

The purpose is to identify and categorize the root causes of a problem, to facilitate brainstorming and collaborative problem-solving and to visually map the relationship between causes and their effects.

Structure of a fishbone Diagram:

1. **Head (Effect):** The problem or outcome being analyzed is placed of the fish (right side of the diagram).
2. **Bones (Categories of causes):** The major categories of potential causes branch out from the spine (main line) of the fish. Common categories include:
 - **People:** human factor or errors.
 - **Processes:** procedures or workflow issues.
 - **Equipment:** machinery or tools.
 - **Materials:** raw materials or resources
 - **Environment:** External or situational factors.
 - **Management:** Policies or decision-making.
3. **Sub-Bones (Specific Causes):** smaller branches under each category represent specific causes or contributing factors.

Chapter Four: Data analysis and interpretation

Introduction

The purpose of this chapter is to present and analyze the data collected through interviews, surveys, observations, and secondary sources, in alignment with the research objectives.

This chapter presents the findings derived from the collected data and interprets them in relation to the research objectives. Both qualitative and quantitative analyses are performed to identify patterns, trends, and key insights related to maintenance practices and machine availability in the cement factory.

4.1 Research Design and Data Collection methods Overview

Data were collected through structured surveys, semi-structured interviews, and maintenance log reviews

4.2 Root Cause Analysis All critical machines table (RCA)

Table 0-1 Root cause analysis for all machines

Reasons	Sum of Down time	% of Down time	Cumm. % of Down time
Machine	53,231.75	68.58%	68.58%
Material	10,783.77	13.89%	82.47%
Method	7,839.23	10.10%	92.57%
Env.	4,545.63	5.86%	98.43%
Planned maintenance	710.83	0.92%	99.35%
Man	511.54	0.66%	100%
Grand Total	77,622.75	100.00%	

The table provides a breakdown of downtime reasons for the (All) machine, highlighting their relative impact on overall operational disruptions. Machine -related issues account for the largest share of downtime at 69 % (53,232 hours, followed by Material method-related problems at 10% (7,839 hours).

4.2.1 Root Cause Analysis Table of Crusher:

Table 0-2 Root cause analysis of crusher

Reasons	Sum of Down time	% of Down time	Cumm. % of Down time
Machine	9,354.80	52.03%	52.03%
Method	6,067.48	33.75%	85.78%
Material	1,572.54	8.75%	94.53%
Env.	891.08	4.96%	99.49%
Man	93.14	0.52%	100%
Grand Total	17,979.04	100.00%	

The table provides a breakdown of downtime reasons for the (Limestone Crusher line one, two & Additive crusher Items) machine, highlighting their relative impact on overall operational

disruptions. Machine -related issues account for the largest share of downtime at 52 %(9,355 hours, followed by Method method-related problems at 34% (6,067 hours).

4.2.2 Root Cause Analysis table of raw mill:

Table 0-3 Root cause analysis of Raw mill

Reasons	Sum of Down time	% of Down time	Cumm. % of Down time
Machine	10,091.32	90.67%	90.67%
Env.	737.00	6.62%	97.29%
Material	180.05	1.62%	98.91%
Method	121.83	1.09%	100.00%
Total	11,130.20	100.00%	

The table provides a breakdown of downtime reasons for the (Multiple Items) machine, highlighting their relative impact on overall operational disruptions. Machine -related issues account for the largest share of downtime at 91 %(10,091 hours, followed by Environment Method-related problems at 1% (122 hours).

4.2.3 Root Cause Analysis table of Kiln:

Table 0-4 Root cause analysis of Kiln

Reasons	Sum of Down time	% of Down time	Cumm. % of Down time
Machine	6,673.51	76.59%	76.59%
Env.	790.70	9.07%	85.66%
Planned maintenance	710.83	8.16%	93.82%
Method	538.58	6.18%	100.00%
Total	8,713.62	100.00%	

The table provides a breakdown of downtime reasons for the (Multiple Items) machine, highlighting their relative impact on overall operational disruptions. Machine -related issues account for the largest share of downtime at 77 %(6,674 hours, followed by Environment Method-related problems at 6% (539 hours).

4.2.4 Root Cause Analysis table of cement mill:

Table 0-5 Root cause analysis of Cement mill

Reasons	Sum of D. time	% of D. time	Cumm. % of D.time
Machine	17,207.58	87.82%	87.82%
Env.	1,252.32	6.39%	94.21%
Material	637.59	3.25%	97.46%
Method	406.19	2.07%	99.53%
Man	90.90	0.46%	100.00%
Total	19,594.58	100.00%	

The table provides a breakdown of downtime reasons for the (line one and two cement mill) machine, highlighting their relative impact on overall operational disruptions. Machine -related issues account for the largest share of downtime at 88 %(17,208 hours, followed by Environment Method-related problems at 2% (406 hours).

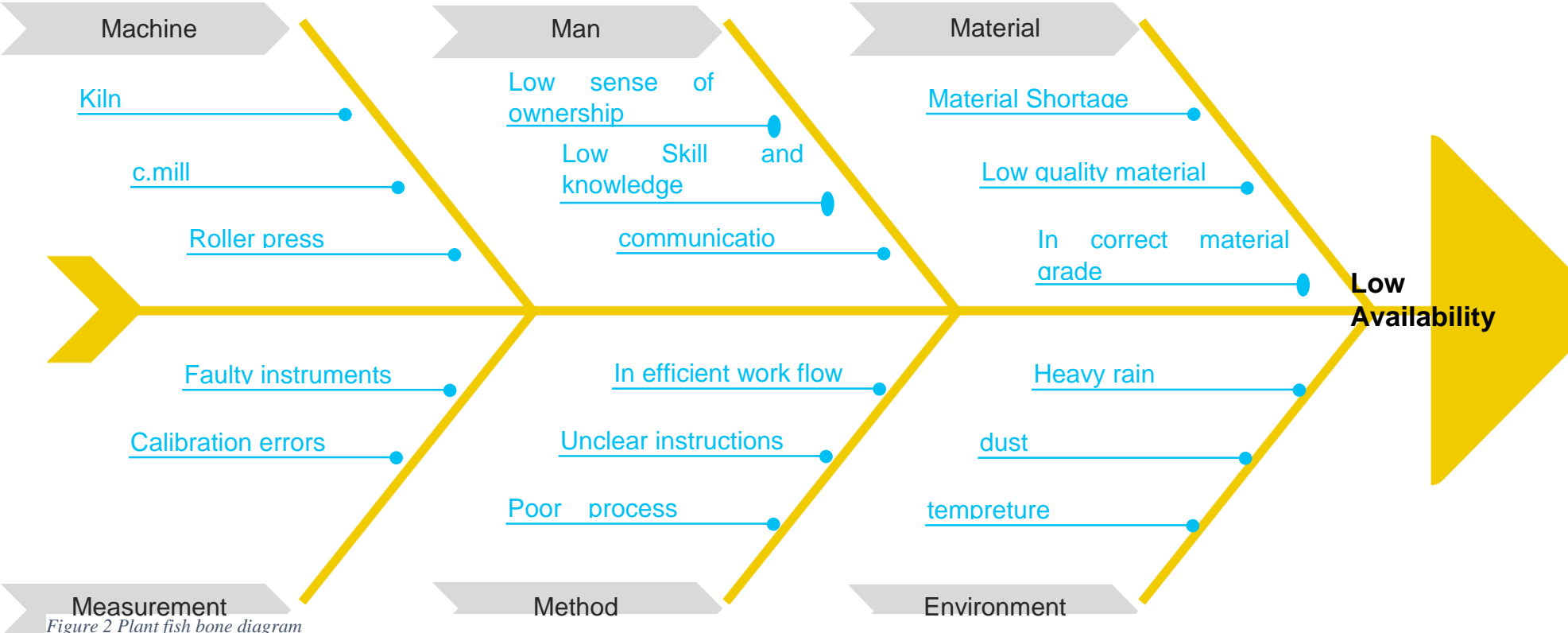
4.2.5 Root Cause Analysis table of Packing

Table 0-6 Root cause analysis of packing

Reasons	Sum of Down time	% of Down time	Cumm. % of Down time
Machine	9,904.54	49.02%	49.02%
Material	8,393.59	41.54%	90.56%
Env.	874.53	4.33%	94.89%
Method	705.15	3.49%	98.38%
Man	327.50	1.62%	100.00%
Total	20,205.31	100.00%	100.00%

The table provides a breakdown of downtime reasons for the (Multiple Items) machine, highlighting their relative impact on overall operational disruptions. Machine -related issues account for the largest share of downtime at 49 % (9,905 hours, followed by Material method-related problems at 3% (705 hours).

Plant FISHBONE DIAGRAM



The fishbone diagram highlights low machine availability as the central issue plaguing plant operations, with interconnected root causes spanning multiple categories. Equipment breakdowns in critical machinery like the cement mill, kiln and roller press (potentially exacerbated by poor maintenance practices and operator skill gaps) directly reduce uptime. Human factors, such as a low sense of ownership and inadequate training among staff, lead to delayed troubleshooting and inconsistent upkeep of machines. Compounding these challenges, material shortages and incorrect material grades force machines to idle while awaiting inputs, while faulty instruments and calibration errors mask underlying mechanical issues, allowing minor problems to escalate into prolonged downtime. Environmental stressors like dust and temperature fluctuations further strain equipment reliability, and inefficient workflows marked by unclear instructions and poor processes slow response times to machine failures. Together, these factors create a cycle of reduced productivity, where machines are either non-operational, under maintained, or misused, underscoring the need for targeted interventions in maintenance protocols, operator training, and supply chain coordination to restore consistent machine availability.

4.3 Quantitative Data Analysis

4.3.1 Description analysis of survey questions and finding, Interpretation and Implication

1: Analysis of Existing Maintenance Practices: This section evaluates how well the current maintenance strategies align with industry best practices.

Table 0-7 Existing maintenance practice

1: Existing Maintenance Practices								
S.n	Statement		Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)	Total
1	The current maintenance system is effective in minimizing machine downtime.	n	8	17	5	0	0	30
		%	26.6	56.6	16.6	0	0	100
2	Maintenance schedules are strictly followed and well-documented.	n	0	14	12	4	0	30
		%	0	46.6	40	13.3	0	100
3	Preventive maintenance is given priority over corrective maintenance.	n	0	15	10	5	0	30
		%	0	50	33.3	16.6	0	100
4	The current maintenance strategy significantly impacts machine availability.	n	2	15	9	4	0	30
		%	6.6	50	30	13.3	0	100

5	Spare parts availability is sufficient to meet maintenance needs.	n	3	20	7	0	0	30
		%	10	66.6	23.3	0	0	100
Total		n	13	81	43	13	0	150
		%	8.6	54	28.6	8.6	0	100

1.1 Effectiveness of the Current Maintenance system in minimizing machine downtime

A clear sign of major system problems, 56.67% of respondents questioned whether the current maintenance system was helpful in reducing downtime, with none agreeing and only 16.67% being neutral. This agreement highlights a serious operational risk: antiquated or reactive procedures are probably not maintaining equipment availability, which reduces productivity. The findings call for immediate action to buck this trend, moving away from Band-Aid solutions and toward data driven predictive maintenance plans. Without these changes, the dangers of ongoing downtime would increase, hindering plant productivity and competitiveness in a time when uptime is equated with revenue.

1.2 Maintenance schedules and documentation

Demonstrating clear evidence of system dysfunction, Nearly half (46.67) of respondents disagreed with following maintenance schedules, while 40% were neutral and only 13.33% agreed. This pervasive lack of consistency in schedule compliance and documentation points to haphazard methods, where inadequate planning and disregarded procedures probably lead to avoidable malfunctions. Prioritizing strict schedule enforcement and careful record-keeping is essential to reducing unscheduled downtime. In addition to reducing reoccurring problems, easily readable documentation would change maintenance from a reactive jumble to a simplified, proactive process a fundamental change for dependability and effectiveness.

1.3 Priority of preventive Maintenance over corrective Maintenance

A clear sign that reactive fix-on-failure procedures predominate is the fact that half of respondents objected and a third were undecided about preventive maintenance (PM) being given priority over corrective maintenance. Operations are caught in a vicious circle of unscheduled malfunctions, exorbitant expenses, and unpredictable downtimes due to this dependence on corrective maintenance. Prioritizing planned inspections and predictive techniques could reduce emergency repairs, extend equipment life, and stabilize productivity turning maintenance from a cost driver to a dependability cornerstone and is necessary to break free.

1.4 Impact of maintenance strategy on machine availability

A clear sign of institutional weakness, half of the respondents denied that existing maintenance practice significantly increase machine availability, while another 30% expressed neutrality. This general suspicion indicates that current strategies are not maintaining equipment uptime,

endangering operational effectiveness. It is essential to rethink the approach in order to close this gap, giving sophisticated techniques like condition-based or predictive maintenance top priority. In the absence of such modernization, poor machine availability could lead to extended downtime, which hinder output and weaken the plant’s competitive advantage.

1.5 Spare parts Availability

A significant bottleneck that is impairing maintenance efficiency was revealed when 66.67% of respondents pointed out insufficient spare parts availability, with nearly a quarter (23.33%) remaining undecided. This pervasive dissatisfaction indicates that factory productivity is being slowed down and downtime is being prolonged due to delayed repairs that are caused by inconsistent part access. The data calls for immediate improvements to inventory management systems and closer ties with suppliers in order to stop the hemorrhage, guaranteeing prompt repairs and smooth production flow. In an industry where speed is essential for existence, ignoring this could force the facility into vicious cycle of avoidable delays and reduce its competitiveness.

2: Machine downtime and root causes

Table 0-8 Machine downtime and root causes

2: Machine Downtime and Root Causes								
S.n	Statement		Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)	Total
1	Machine failures significantly impact production efficiency.	n	0	0	0	5	25	30
		%	0	0	0	16.6	83.3	100
2	Unexpected breakdowns occur frequently in critical equipment.	n	0	0	13	17	0	30
		%	0	0	43.3	56.6	0	100
3	The root causes of machine failures are systematically analyzed and addressed.	n	0	11	4	15	0	30
		%	0	36.6	13.3	50	0	100
4	The maintenance team is adequately trained to diagnose and repair failures.	n	2	4	9	15	0	30
		%	6.6	13.3	30	50	0	100
5	A lack of predictive maintenance contributes to unplanned downtimes.	n	0	0	5	20	5	30
		%	0	0	16.6	66.6	16.6	100
Total		n	2	15	31	72	30	150
		%	1.3	10	20.6	48	20	100

2.1 Impact of machine failures on production efficiency

Machine failures were unanimously cited by all respondents as a severe impediment to production efficiently, with 83.33% strongly agreeing and 16.67% agreeing. This consensus emphasizes how

equipment failures and halted workflows are directly related and disruptive, indicating that reactive solutions are no longer practical. The way forward necessitates a paradigm shift in order to recover productivity: integrating robust reliability tactics and predictive maintenance technologies to prevent problems rather than just react to them, ignoring this requirement could result in more expensive disruptions, but addressing it could turn maintenance from a firefighting exercise into a driving force behind smooth, high-yield operations.

2.2 Frequency of unexpected breakdowns

According to a survey, a clear sign of systematic dependability gaps is that 56.7% of participants accept regular unexpected malfunctions in vital equipment, while 43.3% stay indifferent. Due to reactive maintenance procedures, insufficient predictive systems, or inadequate equipment monitoring, this pattern indicates that unplanned breakdowns are common. These interruptions lead to expensive production stops, highlighting the urgent need to switch from crisis-driven solutions to proactive ones. Condition-based monitoring and predictive maintenance could reduce the frequency of breakdowns, stabilize operations, and turn maintenance from a source of lost productivity into a vital component of operational resilience.

2.3 Root cause analysis of machine failures

While half of respondents agree that machine malfunctions are subjected to systematic root cause analysis (RCA), more than a third consent this rigor, according to the report, which shows a mixed viewpoint on failure management. This discrepancy indicates gaps in the investigation of failures that could lead to reoccurring problems if underlying causes are not identified. This gap might be closed by enhancing RCA procedures, which would turn Band-Aid solutions into proactive, evidence-based initiatives. Organizations may prevent recurring failures, minimize downtime, and strengthen long term operational resilience by incorporating organized problem solving into maintenance workflows. This allows them to transform reactive setbacks into strategic improvements.

2.4 Training and competency of maintenance team

According to the poll, although half of participants believe the maintenance personnel is well trained, a significant 30% express no opinion, indicating ambiguity or deficiencies in specialist knowledge, especially in more complex domains like predictive maintenance. This ambiguity draws attention to a crucial weakness: even proficient teams run the risk of becoming obsolete if they don't adapt to changing technical needs. Investing in organized, continuous training programs that emphasize contemporary expertise and match worker capabilities with the maintenance issues of the future.

2.5 Predictive maintenance and unplanned downtime

The perceived importance of predictive maintenance in preventive equipment breakdowns was shown by the startling 83% of respondents who connected unscheduled downtimes to its lack. This agreement points to a clear operational weakness: predictive systems might serve as a safety net by

spotting early failure indicators, but reactive solutions expose facilities to preventable disruptions. By using such strategies, maintenance would be transformed from a costly gunfight to a proactive driver of productivity and resource management, reducing downtimes and increasing equipment reliability.

3: Adoption of modern maintenance systems

Table 0-9 Adoption of modern maintenance system

S.n	Statement		Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)	Total
1	Predictive maintenance can reduce machine downtime and improve OEE.	n	0	0	2	8	20	30
		%	0	0	6.666667	26.6667	66.66667	100
2	Condition-based maintenance is more effective than traditional preventive	n	0	4	9	17	0	30
		%	0	13.33333333	30	56.6667	0	100
3	Implementing modern maintenance technologies is feasible within our	n	0	0	6	18	6	30
		%	0	0	20	60	20	100
4	The management supports the adoption of digital maintenance tools.	n	2	9	15	4	0	30
		%	6.666666667	30	50	13.3333	0	100
5	Advanced data analytics can enhance maintenance decision-making.	n	0	0	5	7	18	30
		%	0	0	16.66667	23.3333	60	100
Total		n	2	13	37	54	44	150
		%	1.333333333	8.666666667	24.66667	36	29.33333	100

3.1: Predictive maintenance and OEE Improvement

With more than 80% of respondents agreeing or strongly agreeing that predictive maintenance has revolutionary potential to reduce machine downtime and overall equipment effectiveness (OEE), there was broad agreement among the respondents. This resounding support positions it as a critical investment for the facility and highlights a common belief in its capacity to improve machine availability and operational performance. It is obvious that incorporating predictive maintenance might lead to a dual benefit: increasing production efficiency through enhanced OEE and reducing unnecessary maintenance costs, which would ultimately push the plant toward leaner, more robust operations.

3.2: Condition-Based Maintenance vs. Traditional Maintenance

A move toward data driven, responsive tactics is indicated by the majority of respondents (56.67%) who confirmed that condition-based maintenance (CBM) performs better than conventional preventive techniques. This inclination highlights an increasing understanding that real-time machine monitoring, as opposed to strict schedules, maximizes resource efficiency and reduces unnecessary interventions. Organizations can achieve leaner operations by prioritizing maintenance only when performance measurements indicate decline. This will reduce expenses,

increases increase equipment lifespans, and maximize uptime. By combining accuracy and usefulness in industrial contexts, this shift from calendar-based procedures to adaptive CBM has the potential to completely rethink maintenance programs.

3.3: Feasibility of Implementing Modern Maintenance Technologies

The integration of contemporary maintenance technologies, such as predictive analytics and IOT sensors, is both feasible and practical given the factory's current operational environment, according to a starting 80% of respondents (60% agreeing, 20% strongly agreeing). This agreement points to a workforce that is prepared to embrace cutting-edge solutions, indicating both infrastructure and cultural preparedness. Reliability, efficiency, and long-term competitiveness are increased by the results, which support strategic investments in these tools and position them as catalysts to move maintenance from reactive fixes to proactive optimization.

3.4 management support for digital maintenance tools

The survey's findings show conflicting opinions: half of participants agree that management supports digital maintenance technologies, while 30% disagree, indicating a lack of unity in commitment. This ambivalence raises the possibility of a halt in the optimization of maintenance operations due to a reluctance to fully embrace technological adoption. Leadership must shift from hesitant support to steadfast advocacy when it comes to allocating resources, coordinating goals, and cultivating an innovative culture if firms are to realize the efficiency advantages that digital tools promise. Even the most revolutionary tools run the risk of being underutilized without unified support, so wasting operational potential.

3.5 Data analytics in maintenance decision- making

With 23% agreeing and 60% strongly agreeing that advanced data analytics can transform maintenance decision making, there was broad agreement among respondents. This demonstrates a common conviction that data can be used to turn reactive tactics into proactive ones, providing real-time insights into machine health, performance trends, and new threats. Maintenance teams may shift from making educated guesses to precision driven interventions that optimize resource allocation, prevent equipment failures, and save operating expenses by converting raw data into actionable insight. The consequence is obvious: incorporating analytics is not only a technology advancement but also a cultural change toward evidence-based agility, where efficiency is synonymous with resilience takes the place of fighting fires.

4: Challenges and recommendations

Table 0-10 Challenges and maintenance system

S.n	Statement		Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)	Total
1	Resistance to change is a major barrier to implementing modern maintenance techniques.	n	11	15	4	0	0	30
		%	36.66666667	50	13.333333	0	0	100
2	A lack of technical expertise prevents the adoption of predictive maintenance.	n	4	16	6	4	0	30
		%	13.33333333	53.33333333	20	13.3333	0	100
3	Investing in modern maintenance systems is cost-effective in the long run.	n	0	0	7	5	18	30
		%	0	0	23.33333	16.6667	60	100
4	Training and up skilling of maintenance personnel is essential for modernization.	n	0	0	8	10	12	30
		%	0	0	26.66667	33.3333	40	100
5	Management should prioritize transitioning to modern maintenance practices.	n	0	0	0	12	18	30
		%	0	0	0	40	60	100
Total		n	15	31	25	31	48	150
		%	10	20.66666667	16.66667	20.6667	32	100

4.1 Resistance to change in adopting modern maintenance techniques

This finding does not entirely disprove cultural inertia, even is 86.7% of respondents (50% disagreeing, 36.7% strongly disagreeing) rejected resistance to change as a significant obstacle to using modern maintenance procedures. According to the research, localized hesitancy such as within particular departments or because of unresolved cultural norms may nonetheless impede development even though widespread rejection is rare. Organizations should prioritize focused education and aggressively foster innovation-friendly settings to maintain momentum, making sure that even minority resistance doesn't impede the long-term advantages of modern maintenance techniques.

4.2 Lack of technical Expertise for predictive maintenance

Skill shortages are not the main obstacle to the implementation of predictive maintenance, as indicated by the survey's findings that more than half (53.33%) of respondents disagreed and 20% were neutral regarding the lack of technical skills. This implies that rather than being only due to technical inability, significant obstacles may be found elsewhere, most often in budgetary constraints, resource distribution, or leadership buy-in. The disagreeing and neutral responses, however, continue to suggest areas of skills while addressing structural restrictions (money, prioritizing). Organizations can remove obstacles and develop a cultural prepared to fully utilize predictive maintenance by refocusing efforts on these interconnected issues.

4.3 cost-effectiveness of modern maintenance systems

A noteworthy 76.7% of respondents agreed that contemporary maintenance systems are cost-effective over the long run, indicating broad trust in their capacity to recoup initial expenditures through ongoing operational savings and efficiency improvements. This agreement highlights a strategic opportunity: giving priority to these technologies is not just a technical advancement but also a wise financial move that promises to turn short-term capital expenditures into long-term productivity gains and more cost-effective cost structures.

4.4 Importance of training and up-skilling maintenance personnel

According to the research, there is broad agreement among stakeholders: 73.33% of them underline that training and up-skilling are essential to workforce modernization, with 40% strongly agreeing and 33.33% agreeing. This emphasizes a crucial requirement: implementing sophisticated maintenance procedures successfully requires not only the deployment of new technologies but also the training of the staff members to use them efficiently. Even state-of-the-art approaches run the risk of underperforming because of knowledge gaps if focused skill development is not implemented. The conclusion is unmistakable. Companies need to give priority to organized, flexible training initiatives that connect technical proficiency with changing operational requirements. The foundation of sustainable modernization, investing in human capital, ensures that innovations result in measurable efficiency benefits rather than untapped potential.

4.5 Management should prioritize transitioning to modern maintenance practices

Respondents unanimously agreed that leadership must give upgrading maintenance procedures top priority, a blatant call for organizational reform, with 60% strongly agreeing and 40% agreeing. The workforce's belief that proactive management is essential to achieving operational efficiency and maintaining competitiveness is demonstrated by this group's position. The results indicate a pressing need for leaders to drive this change by coordinating training, technology, and resource allocation investments with the workforce's openness to innovation. Organizations run the risk of stagnating if they don't take immediate action, which puts them in a position to turn maintenance from a normal task into a strategic growth lever.

5 Impact of Maintenance on overall equipment effectiveness (OEE)

Table 0-11 Impact of maintenance on OEE

S.n	Statement		Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)	Total
1	Improved maintenance practices have led to better OEE performance.	n	0	0	0	13	17	30
		%	0	0	0	43.3333	56.66667	100
2	Downtime reduction through effective maintenance has enhanced productivity.	n	0	0	0	14	16	30
		%	0	0	0	46.6667	53.33333	100
3	Proper maintenance scheduling contributes to better machine availability.	n	0	0	0	10	20	30
		%	0	0	0	33.3333	66.66667	100
4	Real-time monitoring of machine performance can improve OEE.	n	0	0	0	15	15	30
		%	0	0	0	50	50	100
5	OEE measurement helps in identifying maintenance improvement areas.	n	0	0	0	13	17	30
		%	0	0	0	43.3333	56.66667	100
Total		n	0	0	0	65	85	150
		%	0	0	0	43.3333	56.66667	100

5.1 Impact of improved maintenance on OEE performance

There is broad agreement, according to the data: 43.33% of respondents agreed and 56.67% strongly agreed that improved maintenance procedures directly increase overall equipment effectiveness (OEE). This almost complete alignment highlights the workforce's understanding of maintenance as a key factor in equipment productivity and dependability a vital tool for reducing waste and downtime. The consequence is obvious giving proactive, data driven maintenance top priority is a strategic catalyst rather than merely a procedural change. Organizations can turn OEE from a measure into a cultural pillar that promotes competitive resilience and long term operational excellence in resource-intensive settings by institutionalizing these practices.

5.2 Downtime reduction and enhanced productivity

With 53.33% strongly agreeing and 46.67% agreeing that lowering downtime through efficient maintenance has greatly increased productivity, there was broad agreement among respondents. This almost uniform opinion highlights the importance of minimizing downtime as a fundamental component of operational efficiency, where proactive maintenance techniques avoidance of malfunctions and smooth workflows are seen as essential to maintaining ongoing, smooth production. The conclusion is giving targeted maintenance procedures top priority would reduce expensive disruptions and increase plant output overall, making downtime reduction a direct lever for gaining quantifiable productivity gains and a competitive edge.

5.3 Maintenance scheduling and machine availability

All respondents agreed that systematic maintenance scheduling is essential to maximizing machine availability, with 66.67% strongly agreeing and 33.33% agreeing. This emphasizes its function as a pillar of operational reliability since companies may significantly reduce unscheduled outages and maintain steady uptime by anticipating and meeting equipment needs. This indicates a clear road forward for facility. Improving scheduling procedures will release latent capacity and stabilize production rhythms, turning maintenance from a reactive expense into a proactive engine of development and productivity.

5.4 Real time monitoring of machine performance and OEE

All survey participants concurred that increasing overall equipment effectiveness (OEE) requires real time machine performance monitoring. Proactive modifications are made possible by continuous tracking, which keeps minor problems from developing into expensive by providing actionable insights that lay the foundation for data driven decision making, predictive maintenance, and maximized plant efficiency moving operations from reactive firefighting to strategic, preemptive excellence.

6: Digitalization and smart maintenance

Table 0-12 Digitalization and smart maintenance

S.n	Statement		Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)	Total
1	The factory is adopting digital tools for maintenance planning.	n	8	5	7	10	0	30
		%	26.66666667	16.66666667	23.333333	33.33333	0	100
2	IoT-based sensors can enhance condition-based maintenance.	n	0	0	12	14	4	30
		%	0	0	40	46.6667	13.33333	100
3	Digital maintenance logs improve response times and record-keeping.	n	0	0	0	18	12	30
		%	0	0	0	60	40	100
4	Data-driven decision-making is key to optimizing maintenance strategies.	n	0	0	0	12	18	30
		%	0	0	0	40	60	100
Total		n	8	5	19	54	34	120
		%	6.666666667	4.166666667	15.83333	45	28.33333	100

6.1: Adoption of digital tools for maintenance planning

The factory's journey toward digital adoption in maintenance planning indicates a divided position, over a quarter of stakeholders strongly oppose the transition, indicating systematic impediments or deep-seated resistance, while a third of stakeholders acknowledge some of digital tools. This discrepancy implies that fragmented growth is fostered by partial technological integration that ignores cultural resistance, talent gaps, or poor infrastructure. The future requires more than just buying software to unleash efficiency advantages, it also calls for developing digital literacy through focused training, demythologizing tools to align workflows, and building confidence in data driven planning. By bridging this gap, maintenance could be transformed from

a reactive task to a strategic asset that strikes a balance between technical potential and human preparedness.

6.2: IOT- Based sensors for condition based maintenance

The majority of respondents (60%) express great trust in real time equipment monitoring as a tool to anticipate breakdowns and maximizing interventions, acknowledging the transformative potential of IOT based sensors in advancing condition based maintenance. This agreement highlights a trend toward data driven maintenance cultures, where staff are empowered to take proactive measures to reduce downtime and improve accuracy through ongoing sensor derived insights. The results support IOT integration as a strategic tool to transform predictive analytics into real operational resilience and cost savings, rather merely as a technical advancement.

6.3: Digital maintenance logs and their benefits

A resounding 60% of respondents agreed and 40% strongly agreed that digital maintenance logs improve response times and record keeping, indicating a clear need for modernization. This agreement emphasizes how digitization improves operations by substituting real time, searchable data for error prone paper trails, which speeds up accountability and issue resolution. The change signifies a fundamental improvement in addition to efficiently gains, accurate digital records reduce human errors, facilitate predictive analytics, and produce an auditable maintenance history. This results in fewer downtime emergencies, better resource allocation, and a proactive rather than reactive reliability culture for plant operations, putting facilities in a position to use data as a strategic asset in an increasingly interconnected industrial landscape.

6.4: data driven decision making for optimizing maintenance strategies

According to survey results, there is broad agreement that data driven decision making is essential for maximizing maintenance efforts, with 60% strongly agreeing and 40% agreeing. This demonstrates the revolutionary role analytics play in improving procedures, firms can systematically improve maintenance performance by using data to foresee problems, priorities jobs, and allocate resources effectively. The consequence is obvious, investing in strong data analytics capabilities will improve maintenance accuracy while also enabling cascade improvements in resource usage and plant wide efficiency, putting businesses in a position to anticipate disturbances rather than just respond to them.

4.4 Discussion and Interpretation

- The analysis shows that low availability and OEE across the cement plant's critical lines (kiln, cement mill, raw mill, and packing) are caused by a complex interaction of operational, technical, and organizational issues. The facility's primary issue is a reactive maintenance culture, which results in uneven application of predictive and preventive techniques. Due to inadequate documentation and the omission of preventive duties during periods of high production, more than 56% of respondents disagreed that the current maintenance system successfully minimizes downtime. Aging infrastructure, frequent

equipment failures (such as bucket elevators chain breaks and roller press liquid starter malfunctions), and power grid instability all contribute to this reactive strategy, which has resulted in more than 30 instances of motor and cable damage.

- Downtime is made worse by inefficient material handling. Production flow is disrupted by obstruction in chutes, bins, and dosimats, which are frequently caused by clumping caused by moisture or large clinker fragments, shortages of spare parts exacerbate these problems, according to 66.7% of respondents, there is not enough inventory, which results in lengthy repairs. Raw material shortages were made worse by procurement procedures that put cost ahead of supplier dependability, especially during kiln stoppages.
- Human elements are also very important. While out of date training programs left workers unprepared for cutting edge equipment like vibration analysis or IOT sensors, skill gaps caused delays in defect identification and repairs. A lack of established procedures was brought to light by operational failures, such as unintentional emergency stops brought on by inadequately labeled control panels. These problems were made worse by management stability just 50% of respondents agreed that leadership encourages the deployment of digital tools.
- In terms of technology, the factory is slow to implement digital systems and predictive maintenance. The facility uses excel and manual records for tracking, even though it recognizes the potential of IOT sensors (83% related unscheduled downtime to a lack of predictive maintenance). Sensor malfunctions and false alarms, frequently brought on by dust buildup or inadequate calibration, compromised the accuracy of the data, and siloes systems caused delayed material scarcity signals (e.g. weighbridge-ERP disconnection).
- There are clear opportunities for improvement. More than 60% of those surveyed firmly believed that long term cost benefits might be achieved by investing in contemporary maintenance systems (such as CMMS and predictive tools). 50% of respondents strongly agreed that real time monitoring and data analytics might improve decision making, making them essential for OEE benefits. Bottlenecks could be eliminated by process improvements such automating conveyor inspections, adding humidity controls in silos, and upgrading crushers to minimize clinker size. The readiness of the workforce is encouraging 60% of respondents said it was possible to switch to current procedures as long as management gave training top priority and set KPIs that balanced documentation, timeliness, and quality.
- In conclusion, systemic deficiencies in infrastructure, digital adoption, and maintenance strategy are the cause of the plant's low OEE and availability. In order to address these, a change from reactive to predictive procedures is necessary, supported by cross departmental cooperation, strategic technology investments, and staff up skilling. The future depends on coordinating organizational culture with long-term operational excellence, as 73% of respondents view training as crucial and 60% urge leadership to give modernization top priority.

4.5 Summary of key findings

Overall equipment effectiveness (OEE) and machine availability were directly impacted by the study's identification of systemic opportunities and problems in the cement factory's maintenance practices:

4.5.1 Reactive maintenance culture

Over half (56.7%) of respondents expressed skepticism that existing maintenance practices effectively minimize downtime, citing a cycle of reactive fixes over proactive care. During peak production periods, preventive maintenance (PM) tasks critical for sustaining reliability were frequently not prioritized or skipped entirely to meet output targets. Compounding this, aging infrastructure, such as ID fan motors and roller presses prone to wear and tear, exacerbated breakdown frequencies, creating a costly of unplanned stoppages and rushed repairs. This highlights a systematic tension between short term productivity demands and the long term operational stability needed to sustain equipment health.

Three enduring problems were the main causes of the facility's productivity problems, frequent material flow bottlenecks, such as recurrent silo and bin jams, which stopped production lines unpredictable power supply disruptions, which caused over 30 grid failures per month and crippled continuous operations and chronic shortages of spare parts, where two thirds of maintenance teams reported critical inventory gaps, which delayed repairs. These issues combined to create a triangle of inefficiencies that compromised maintenance responsiveness and output stability.

4.5.2 Human and Organizational Gaps:

Rigid silos between the divisions of production, asset management, and marketing, coupled with ongoing skill gaps in troubleshooting capabilities, caused a delay in the resolution of crucial issues. This segmentation hampered coordination during emergencies like labor strikes or material shortages, teams worked in parallel instead than together, which harmed operational cohesion and response times. Bottlenecks remained unsolved due to a lack of common procedures or communication channels, demonstrating how organizational divisions and competency deficiencies intensify disruptions under pressure. Even if the need of digital transformation is becoming more widely acknowledged, half of the stakeholders who responded to the poll pointed out a significant obstacle, uneven leadership support for contemporary tools. Teams become skeptical and modernization efforts get fragmented as a result of this inconsistent backing, which slows down progress. Even while new technologies promise to increase efficiency, their adoption fails in the absence of consistent executive support, leaving efforts underfunded or out of step with strategic priorities.

4.5.3 Technological Underutilization

Proactive maintenance was limited by the use of excel for PM tracking and inaccurate sensor readings (such as false vibration warnings). Despite this, 80% of respondents confirmed that CMMS adoption is feasible, and 83% connected unscheduled downtime to a lack of predictive maintenance.

Chapter 5 Conclusion and Recommendations

5.1 Conclusion

This study emphasizes how outmoded procedure, technological stagnation, and organizational silos interact to cause the cement factory's low OEE and machine availability. The research used mixed methods quantitative and qualitative approach. Through a comprehensive case study approach analyze maintenance data in terms of performance metrics and downtime cases. The research findings highlighted several critical issues. A reactive maintenance culture prevailed, with over 56% of respondents indicating that preventive tasks were often skipped during peak production periods. Aging infrastructure and unstable power supply led to more than 30 major equipment failures annually. Material handling inefficiencies, such as moisture induced blockages and oversized clinker disruptions, further strained operations, exacerbated by a persistent shortage of spare parts 66.7% of respondents cited inventory inadequacies as a major bottleneck. Furthermore, outdated manual record keeping practices undermined data accuracy, despite 83% of participants acknowledging the link between downtime and the absence of predictive maintenance. Despite these challenges, the study identified several opportunities for improvement. Notably, 60% of the workforce expressed support for modernization efforts, while 50% believed that real time monitoring systems could significantly enhance decision making and efficiency. The research output indicated that implement structured maintenance system significantly enhance plant availability and OEE, resulting in higher production rate and reduce operational costs. This research provides action insights for operation facilities aiming to enhance their maintenance practices, there by contributing to improve overall performance in the cement factory. The factory can change from a cost centric, firefighting approach to a data driven, robust operation by implementing predictive technology, streamlining procedures, and investing in human resources. To keep the plant competitive at a time when uptime determines revenue, leadership must take decisive action to match culture, resources, and incentives with long term efficiency goals.

5.2 Recommendations

To address the identified gaps, the following actions are proposed

1. Short-term actions
 - Pilot IOT sensors for real time condition monitoring on high failure equipment (such as cement mill rollers and kiln ID fans).
 - Strict PM schedules should be enforced using digital checklists to increase documentation and get rid of missed work.
 - Update ERP systems for vendor coordination and real time spare parts tracking.
2. Medium term Strategies
 - Implement CMMS to centralize maintenance planning, automate work orders, and integrate predictive analytics.
 - Start training courses for maintenance teams that concentrate on predictive tools (such as vibration analysis and IOT interpretation).

3. Long term goals

- Transition to predictive maintenance as the core strategy, targeting a 20-40% reduction in unplanned downtime.
- Foster cross department collaboration through shared KPIs (e.g., digitalized workflows)
- Encourage leadership support by presenting predictive systems return on investment (ROI), such as the cost savings from fewer malfunctions.

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Appendix A: Survey

Likert Scale Questionnaire: Improving Plant Availability through Effective Maintenance Systems

Section 1: General Information

1. Name (Optional): _____
2. Job Title: _____
3. Department: _____
4. Years of Experience in Maintenance/Operations: _____

Section 1: Existing Maintenance Practices Please indicate your level of agreement with the following statements regarding the current maintenance system in your factory.

Statement	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
1. The current maintenance system is effective in minimizing machine downtime.					
2. Maintenance schedules are strictly followed and well-documented.					
3. Preventive maintenance is given priority over corrective maintenance.					
4. The current maintenance strategy significantly impacts machine availability.					
5. Spare parts availability is sufficient to meet maintenance needs.					

Section 2: Machine Downtime and Root Causes Please rate the following statements based on your experience with machine downtime.

Statement	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
1. Machine failures significantly impact production efficiency.					
2. Unexpected breakdowns occur frequently in critical equipment.					
3. The root causes of machine failures are systematically analyzed and addressed.					
4. The maintenance team is adequately trained to diagnose and repair failures.					
5. A lack of predictive maintenance contributes to unplanned downtimes.					

Section 3: Adoption of Modern Maintenance Systems Please indicate your level of agreement with the following statements regarding modern maintenance systems such as predictive and condition-based maintenance.

Statement	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
1. Predictive maintenance can reduce machine downtime and improve OEE.					
2. Condition-based maintenance is more effective than traditional preventive maintenance.					
3. Implementing modern maintenance technologies is feasible within our factory.					
4. The management supports the adoption of digital maintenance tools.					
5. Advanced data analytics can enhance maintenance decision-making.					

Section 4: Challenges and Recommendations Please indicate your level of agreement with the following statements regarding challenges and the need for improvements.

Statement	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
1. Resistance to change is a major barrier to implementing modern maintenance techniques.					
2. A lack of technical expertise prevents the adoption of predictive maintenance.					
3. Investing in modern maintenance systems is cost-effective in the long run.					
4. Training and up skilling of maintenance personnel is essential for modernization.					
5. Management should prioritize transitioning to modern maintenance practices.					

Section 5: Impact of Maintenance on Overall Equipment Effectiveness (OEE)

Statement	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
1. Improved maintenance practices have led to better OEE performance.					
2. Downtime reduction through effective maintenance has enhanced productivity.					
3. Proper maintenance scheduling contributes to better machine availability.					
4. Real-time monitoring of machine performance can improve OEE.					

Section 6: Digitalization and Smart Maintenance

Statement	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
1. The factory is adopting digital tools for maintenance planning.					
2. IoT-based sensors can enhance condition-based maintenance.					
3. Digital maintenance logs improve response times and record-keeping.					
4. Data-driven decision-making is key to optimizing maintenance strategies.					

Appendix B: Interview Questions

Interview Questions: Improving Plant Availability through Effective Maintenance Systems

Section 1: General Background

1. Can you briefly describe your role and responsibilities in the factory?
2. How many years of experience do you have in maintenance/operations?
3. What type of maintenance strategies does your factory currently use?

Section 2: Existing Maintenance Practices

1. How would you describe the effectiveness of the current maintenance system in minimizing downtime?
2. Are maintenance schedules strictly followed, and how are they documented?
3. What challenges do you face in implementing preventive maintenance?
4. How does the current maintenance strategy impact machine availability and productivity?
5. Are spare parts readily available when needed? If not, what are the primary causes of delays?

Section 3: Machine Downtime and Root Causes

1. What are the most common reasons for machine downtime in your factory?
2. How frequently do unexpected breakdowns occur in critical equipment?
3. What steps are taken to analyze and address the root causes of machine failures?
4. Do you believe that the maintenance team has adequate training to diagnose and repair failures effectively? Why or why not?
5. In your opinion, does the lack of predictive maintenance contribute significantly to unplanned downtimes?

Section 4: Adoption of Modern Maintenance Systems

1. What is your understanding of modern maintenance strategies such as TPM and predictive maintenance, condition-based maintenance?
2. Have you or your team explored implementing these advanced maintenance strategies in the factory?
3. What do you think are the biggest barriers to adopting modern maintenance technologies?
4. How do you think management perceives the transition to modern maintenance systems?
5. In your opinion, how can advanced data analytics improve maintenance decision-making?

Section 5: Challenges and Recommendations

1. What are the main challenges preventing an effective maintenance system in your factory?
2. Do you think resistance to change is a major issue when transitioning to modern maintenance systems? Why?
3. What kind of training or support would be required to successfully implement TPM and predictive maintenance?
4. Do you believe that investing in modern maintenance systems will be cost-effective in the long run? Why or why not?
5. What recommendations would you make to improve maintenance practices in your factory?

Section 6: Impact on Overall Equipment Effectiveness (OEE)

1. How do you measure the impact of maintenance practices on OEE?
2. Have improved maintenance practices led to better OEE performance in your factory?
3. How does downtime reduction through effective maintenance enhance productivity?
4. In your opinion, can real-time monitoring of machine performance significantly improve OEE?
5. Do you believe that OEE measurement helps in identifying areas for maintenance improvement?

Section 7: Digitalization and Smart Maintenance

1. Is your factory currently using any digital tools for maintenance planning? If so, which ones?
2. Do you believe digital maintenance logs can improve response times and record-keeping?
3. How important do you think data-driven decision-making is for optimizing maintenance strategies?

Appendix C

Table 0-1 Availability, Performance and utilization

S.n	Machines	Line	Daily Working Hour	Availability			Utilization		
				Plan	Actual	Performance in	Plan	Actual	Performance
				Daily	Daily	%	Daily	Daily	in %
1	Limestone Crusher	L.One	10	160	211.99	132.494	142.2	193.7	136.21
		L.Two	10	167	112.65	67.4551	146.96	97.1	66.06
2	Additive Crusher	L.Two	10	150	192.08	128.053	131.13	93.6	71.34
3	Raw mill	L.One	22	178	142	79.7753	163.11	137.9	84.52
		L.Two	22	191	126.09	66.0162	172.88	120.6	69.76
4	Kiln	L.One	24	209	155.6	74.4498	209	153.7	73.56
		L.Two	24	256	171.75	67.0898	256	171.1	66.85
5	C.Mill	L.One	22	200	120.39	60.195	188.7	115.4	61.16
		L.Two	20	167	167.35	100.207	147.26	162.9	110.65
6	Packing	L.One	13	220	175.66	79.8455	203.38	124.3	61.1
		L.Two	11.8	200	158.42	79.21	189.83	150.6	79.35

Table 0-2line two downtime

S. n	Working Area	Status	Mechanical	Electrical	Engineering	Supply	PP bag	Process	Power	Sur	Marketing	Sum	D.Time /Daily
1	L. Crusher	Frequency	183	199	25	2		67	25	93		594	
		Down Time /Hr	1677.72	236.33	129.09	8.4		121.74	112.1	145.91		2,431	101
2	A.Crusher	Frequency	55	66	2			60	45	167		395	
		Down Time /Hr	479.76	95.43	1.86			106.06	144.2	405.75		1,233	51
3	Raw mill	Frequency	111	243	11	1		88	66	2		522	
		Down Time /Hr	1299.18	595.76	24.58	24		1650.45	364.2	1.45		3,960	165
4	Kiln	Frequency	33	38	10	1		47	81	1		211	
		Down Time /Hr	862.5	97.47	17.96	24		1599.47	357.4	1.8		2,961	123
5	C.Mill 1	Frequency	180	167	26			162	74	1		610	
		Down Time /Hr	2521.66	260.77	72.53			818.18	237.7	3.3		3,914	163
6	C.Mill 2	Frequency	201	184	35			165	77	1		663	
		Down Time /Hr	1969.49	370.67	66.47			581.14	244.3	0.12		3,232	135
7	Packing-1	Frequency	138	51	15		35	49	46	1	82	417	
		Down Time /Hr	841.61	93.46	36.77		17.91	223.61	125.8	3.1	297	1,639	68
8	Packing-2	Frequency	116	36	16		35	54	23	1	57	338	
		Down Time /Hr	1214.44	78.24	52.99		14.6	406.08	97.45	3.1	351.4	2,218	92
9	Packing-3	Frequency	123	33	13		35	57	24	1	58	344	
		Down Time /Hr	1211.53	67.13	53.04		14.9	415.13	99.84	3.1	362.6	2,227	93
10	Packing-4	Frequency	120	40	14		31	42	39		59	345	
		Down Time /Hr	1092.47	59.85	46.03		13.6	446.23	126.9		345.1	2,130	89

Table 0-3line one downtime

Line One Down Time													
S. n	Working Area	Status	Mechanical	Electrical	Engineering	Auto Garage	Supply	PP bag	Process	Power	Sur Con.	Sum	D.Time /Daily
1	L.Crusher	Frequency	40	305					208	91	162	806	
		D.Time /Hr.	157.76	432.6					252.1	278.56	195.1	1316.12	54.8383
2	Raw mill	Frequency	203	150	20				83	103		559	
		D.Time /Hr.	963.96	719.6	279.97				1157	429.43		3549.96	154
3	Kiln	Frequency	93	86	12				55	117		363	
		D.Time /Hr.	690.09	523	273.64				1069	425.28		2981.01	130
4	C.Mill	Frequency	134	175	23	2	1		65	114		514	
		D.Time /Hr.	1287.1	396.4	427.1	51.7	161		435.3	380.24		3138.64	157
5	Packing-1	Frequency	67	1558	14		3	182	59	38		1921	
		D.Time /Hr.	499.18	94.42	164.3		21.5	284.5	169.9	145.74		1379.52	78
6	Packing-2	Frequency	24	12	1		4	15	25	4		85	
		D.Time /Hr.	1884.8	57.2	97		1711	9.75	246.2	36.37		4042.32	181

Table 0-4 2023/24 plan vs. actual production

2023/25 Plan /Actual and Productivity [43]

Machine	Line One			Line two			Line 1 + 2		
	Plan	Actual	%	Plan	Actual	%	Plan	Actual	%
Limestone Crusher	639,908	634,877.46	99.21387	1,175,716.20	530,185.94	45.0947	1,815,624.20	1,165,063.40	64.1687525
Additive Crusher				563,997.00	331,622.53	58.7986	563,997.00	331,622.53	58.7986337
Raw mill	668,800	380,358.18	56.87174	1,228,800.00	855,361.79	69.6095	1,228,800.00	855,361.79	69.6095207
Kiln	418,000	238,723.86	57.11097	768,000.00	534,240.88	69.5626	1,186,000.00	772,964.74	65.1740927
C.Mill	565,510	277,065.30	48.99388	918,061.00	648,044.34	70.5884	1,483,571.00	925,109.64	62.3569509
Packing	565,510	277,065.30	48.99388	918,061.00	643,344.34	70.0764	1,483,571.00	920,409.64	62.0401477

1- Lime Stone Crusher Line I				2- Lime Stone Crusher Line II				3- Additive Crusher			
S/N	Description	Unit		S/N	Description	Unit		S/N	Description	Unit	
1	Utilization	in %	136.21	1	Utilization	in %	66.06	1	Utilization	in %	71.34
2	Availability	in %	132.494	2	Availability	in %	67.4551	2	Availability	in %	128.05
3	Quality Index	in %	99	3	Quality Index	in %	99	3	Quality	in %	99
4	Performance	in %	99.2	4	Performance	in %	45.1	4	Performance	in %	69.6
5	OEE	in %	131%	5	OEE	in %	30%	5	OEE	in %	89%
4- Raw Mill Line I				5- Raw Mill Line II				6- Kiln Line I			
S/N	Description	Unit		S/N	Description	Unit		S/N	Description	Unit	
1	Utilization	in %	84.52	1	Utilization	in %	69.76	1	Utilization	Days	73.56
2	Availability	in %	79.7753	2	Availability	in %	66.0162	2	Availability	in Days	74.45
3	Quality Index	in %	99	3	Quality Index	in %	99	3	Quality	in %	99
4	Performance	in %	57	4	Performance	in %	69.6	4	Performance	in %	57
5	OEE	in %	45%	5	OEE	in %	46%	5	OEE	in %	42%
7- Kiln Line II				8- Cement Mill Line I				9- Cement Mill Line II			
S/N	Description	Unit		S/N	Description	Unit		S/N	Description	Unit	
1	Utilization	in %	66.85	1	Utilization	in %	61.16	1	Utilization	in %	110.65
2	Availability	in %	67.0898	2	Availability	in %	60.195	2	Availability	in %	100.21
3	Quality Index	in %	99	3	Quality Index	in %	99	3	Quality	in %	99
4	Performance	in %	69.5	4	Performance	in %	49	4	Performance	in %	70.5
5	OEE	in %	47%	5	OEE	in %	29%	5	OEE	in %	71%
10- Packing Line I				11- Cement Packing Line II							
S/N	Description	Unit		S/N	Description	Unit					
1	Utilization	in %	61.1	1	Utilization	in %	79.35				
2	Availability	in %	79.8455	2	Availability	in %	79.21				
3	Quality Index	in %	99	3	Quality Index	in %	99				
4	Performance	in %	49	4	Performance	in %	70				
5	OEE	in %	39%	5	OEE	in %	55%				

Table 0-5Plant 2023/24 Utilization, availability, quality and OEE