UNIVERSITY OF BAHRAIN

College of Engineering

Department of Mechanical Engineering

Improvement of Maintenance Performance of the Instrument Maintenance Section at the Carbon Department of ALBA

A Thesis Submitted in Partial Fulfillment of the Requirements for the M.Sc Degree in Engineering Management

Submitted By:

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استمارة إيداع البحث

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إقرار الباحث بالموافقة على الشروط التالية:

يحق لجامعة البحرين إتاحة وتوفير الرسالة أو الأطروحة المذكورة أعلاه في مكتبة الجامعة أو من خلال موقع الإسهامات البحثية للجامعة أو على نطاق أوسع في الخارج؛ كما ويمكن إعادة طباعة الرسالة إذا اقتضت الحاجة لذلك أو رقمنتها مع إتاحتها على شبكة الأنترنت وذلك حسب تقدير إدارة الجامعة.

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تعتبر هذه الرسالة أو الأطروحة من المواد المحمية والتي تخضع إلى حقوق النشر والتأليف، ولا يجوز نشر أي اقتباس من الرسالة بدون توثيق المصدر.

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Abstract

Recently, maintenance has become a major element in any organization that seeks to stay competitive in the market. Due to globalization and industrialization, the competitions between the organizations have been increased which led to look at maintenance management as a strategic factor to achieve best-in-class performance. There are many studies in industries in developed countries about the maintenance management framework. However, there are no studies conducted in aluminum smelting companies worldwide. This study has been focused on an aluminum smelter company. Aluminum Bahrain (ALBA) company has been selected as a case in this research. The research aim is to study and improve the Instrument Maintenance Section (IMS) performance of the Carbon department to achieve their objectives at the minimum time and cost. The study used a number of methods to collect the data, such as reviewing related literature, company recorders, questionnaires, and in-depth interviews. These methods have identified the gaps between IMS performance and best-world performance. Moreover, the main factors that are influencing the IMS performance had been identified and ranked. Accordingly, an eight-block maintenance management framework has been developed in order to improve the IMS performance. By following the developed framework, the total number of breakdowns and its consequences will be reduced by 82%.

Dedication

I dedicate this thesis to my dear family and friends
for their support and encouragement.

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First and foremost, I would like to extend special thanks to my supervisor, Dr. Mohamed Nabhan and co-supervisor Dr. Bader Al Mannai for the continued guidance and beneficial comments over all the stages of this thesis.

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List of Abbreviations

AC	Air Conditioning
ALBA	Aluminum Bahrain Company
AM	Autonomous Maintenance
BS	British Standard
CBM	Condition Based Maintenance
CM	Corrective Maintenance
CMMIS	Computerized Maintenance Management Information System
CMMS	Computerized Maintenance Management System
CPC	Calcined Petroleum Coke
CTP	Coal Tar Pitch
DC	Direct Current
ERP	Enterprise Resource and Planning
FMEA	Failure Modes and Effects Analysis
GDP	Gross Domestic Product
GPC	Green Petroleum Coke
HMI	Human Machine Interface
IMS	Instrument Maintenance Section
ISO	International Organization for Standardization
JIPM	Japan Institute of Plant Maintenance
KPA	Key Performance Area
KPI	Key performance indicator

LCC	Life-Cycle Costs
LTI	Lost Time Injury
MMF	Maintenance Management Framework
MPI	Maintenance Performance Indicator
MPM	Maintenance Performance Measurement
MTV	Metal Transfer Vehicles
OEE	Overall Equipment Effectiveness
OEM	Original Equipment Manufacturer
PI	Performance Indicators
PLC	Programmable Control System
PM	Preventive Maintenance
RCA	Root Cause Analysis
RCFA	Root Cause Failure Analysis
RCM	Reliability-Centered Maintenance
ROI	Return on Investment
ROR	Rate of Return
SAP	Systems Applications and Products
SHE	Safety, Health, and Environment
SPSS	Statistical Package for the Social Science
TPM	Total Productive Maintenance
TQM	Total Quality Management
TRI	Total Recordable Injuries

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Chapter One

Introduction to the Study

1.1Background

1.2Research Problem

1.3Research Questions

1.4Research Objectives

1.5Research Significance

1.6Research Terminology

1.1 Background

In recent decades, industrial manufacturers and services have experienced wide challenges, including process technologies, customer satisfaction, and global competitiveness. The competitive behavior between manufacturers have increased to serve high quality products with the least cost and time, in order to gain greater customer expectations. In this sense, the effective production system requires great work from all sections of the organization, which must function as one strong and dynamic system. Because any failure in performing small tasks leads to negative consequences that will directly or indirectly affect the production system. Therefore, organizations invest large amounts of money in modifications or purchasing new equipment to increase the quality and capacity of the production, but because of no integration between sections, unskilled operators, and lack of preventive maintenance; the maximum efficiency of the equipment is not obtained. Ahmed (2014), has identified factors that affect the performance of the Mechanical Maintenance of Electricity and Water Authority (EWA). Unavailability of preventive maintenance actions, lack of training and communication between the departments, and absence of maintenance performance measurement are the main factors. It is important to adopt some maintenance management techniques to maximize the performance of organizations, in order to eliminate the occuring wastes and losses in the production system. Husband (1976), stated that the objective of maintenance management is to increase the availability of the production system with the least cost, by minimizing the number of system breakdowns. The benefits of adopting one of the maintenance management systems are to improve the quality of the products, increase the availability time of the equipment, eliminate the accidents, and

increase the morale of the employees (Waghmare et al., 2014). In recent years, managers gradually realized that investment in implementing maintenance management increases the productivity and the profits of the organization rather than a cost center (Nuratirah and Salmiah, 2018; Fore and Mudavanhu, 2011; Obamwonyi et al., 2010). There are several maintenance strategies that can be used to improve the maintenance performance, such as Total Productive Maintenance (TPM), Reliability-Centered Maintenance (RCM), and Preventive maintenance (PM).

Accordingly, successful organizations need to evaluate the performance of maintenance; in order to improve the maintenance practices and to achieve the objectives of the organization. The purpose of this research is to study and improve the present maintenance performance of the Instrument Maintenance Section (IMS) at the Carbon Department of Aluminum Bahrain Company (ALBA). The duties of the IMS are to monitor and maintain the measurement and control devices that are used to maximize the availability of the production systems and minimize their failures.

1.2 Research Problem

Many industrial companies face difficulties in achieving an efficient and effective production system; due to insufficient attention to maintenance management. This lack of attention leads to a number of problems that negatively impact the production and quality system, which causes a huge waste with many losses; due to frequent failures in processes, equipment, and machines. The Instrument Maintenance Section (IMS) at the Carbon Department of Aluminum Bahrain Company (ALBA) has been selected as a

research study to improve its performance. According to the maintenance records, the last five years have shown that the number of breakdowns has increased dramatically; due to a number of repetitive failures in communication systems, Human Machine Interface (HMI) screens and control dampers. For instance, in 2014, 328 failures were reported on communication systems, while in 2018 it has sharply increased to 883 failures. This is an indication of a critical problem that must be identified and improved.

1.3 Research Questions

Based on the above, the main three questions to be answered in this research are:

- What is the present state of maintenance practices in IMS of Carbon Department?
- What are the key factors that affect the performance of IMS?
- What framework can be developed to improve the performance of IMS?

1.4 Research Objectives

The aim of this study is to achieve the following goals:

- To evaluate the present maintenance practices carried out by the IMS to identify the deficiencies from the best practices.
- To determine the main challenges that influence the IMS performance which affects achieving the objectives of the department.
- To identify the main causes of the repetitive failures.

- To develop a conceptual framework based on the present model to improve the IMS performance.

1.5 Research Significance

- The investigation of this subject matter has little attention in the company, and it will assist the Carbon Department in achieving their goals and objectives.
- It will contribute in adopting the latest maintenance management techniques and tools, to improve the maintenance effectiveness of the Carbon Department.
- The research will raise awareness about the benefits of implementing maintenance management practices.
- The research will contribute to the development in the economy of Bahrain; due to the important role of Aluminum Bahrain Company.

1.6 The study's Setting

The study is focused on the IMS practices and the maintenance management tools and techniques, and any issues affecting the maintenance performance. There are three separate plants in the carbon department, which are the Paste plant, Kiln plant, and Rodding plant. IMS has responsibility for the maintenance of all three plants. However, the research will be limited to the Kilns plant, since the number of failures increasing dramatically.

1.7 Research Terminology

Maintenance	It is defined as the combination of all technical and associated administrative actions intended to retain an item in, or restore it to, a state in which it can perform its required function (BS 3811:1993).
Maintenance Management	All activities of the management that determine the maintenance strategy, maintenance objectives, maintenance planning, maintenance control, supervision, and improvement of methods in the organization including the economic aspects (BS 3811:1993).
Preventive Maintenance	Any task designed to prevent failures or mitigate their effects (Sherwin,2000).
Total Productivity Maintenance (TPM)	It consists of a range of methods, which are known from maintenance management experience to be effective in improving reliability, quality, and production (Nakajima,1988).

Chapter Two

Literature Review

2.1 Maintenance Management Concept

2.2 Maintenance Management Objectives

2.3 Maintenance Types

2.4 Maintenance Strategies

2.5 Maintenance Techniques and Tools

2.6 Maintenance Investment

2.7 Maintenance Management Framework

2.1 Maintenance Management Concept

The term maintenance has been defined by many authors and organizations and continued to change over time. In the early years, the maintenance in organizations was not linked to strategy. It was defined as a group of activities that are applied only when the equipment or machine fails (run to fail). This is due to, insufficient awareness of maintenance benefits. In addition, there was an absence of tools and technology that help the maintenance team to monitor the efficiency of their equipment. After World War II, there was a rapid development in science and technology in the concept of maintenance, which led to the occurrence of different definitions of maintenance. However, the main purpose of maintenance remains the same. Maintenance is a group of organized activities that aims to increase the reliability and availability of the equipment or the machine in order to achieve the highest quality with the least cost and time. According to the British Standard Glossary of terms (BS EN 13306:2017), the maintenance is a " combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function". The maintenance activities should be managed properly in order to achieve the optimum plant working condition. The maintenance activities could be monitoring, repairing or replacing any necessary items. These activities become a challenge to the maintenance team; due to its direct effect on the objectives of the organization. For instance, the critical equipment and complex technologies require further actions to be taken, to ensure that the operations function in their best condition. According to Ylipää et al. (2017), the level of the complexity of the production equipment has increased due to the digitalization of the production. These maintenance actions are essential

and they need to be managed effectively in order to guide any organization to the world-class. Therefore, the management of maintenance must be in a manner of enhancing the quality of the work with the least cost.

The maintenance management is defined according to the British Standard Glossary of terms (BS EN 13306:2017) as "all activities of the management that determine the maintenance objectives, strategies and responsibilities, and implementation of them by such means as maintenance planning, maintenance control, and the improvement of maintenance activities and economics". Wienker et al. (2016), state that there is a number of key elements that form the basis of maintenance management including:

(1) An Obvious strategy.
(2) Policies to support the strategy.
(3) Procedures & processes to enable implementation of the strategy & policy.
(4) Tools to support this implementation.
(5) A well-established Maintenance Business Process with checks and balances.

In addition, Gupta (2009), notes that the maintenance management must consist of the following concepts:

(1) Setting aims and objectives.
(2) Providing the means of attaining those aims and objectives.
(3) Decision making.

2.2 Maintenance Management Objectives

The maintenance management acts as the backbone of any organizations. It may break the business of the organizations when the maintenance practices are not managed effectively. Kutucuoglu et al. (2001) emphasized that the plant maintenance is one of the most important parts of the business environment. Therefore, the maintenance management plays an important role in achieving the organizations' objectives and eliminates or minimizes the effect of the downtime of the equipment and machines. Mobley (2004) concludes the objectives of maintenance management as follows:

1- Ensure all productive assets are always in optimum operating conditions.
2- Increase the useful life of the plant equipment.
3- Maximize the utilization of all plant assets.
4- Ensure the safety of the manpower and the environment by controlling the workplace hazards.
5- React quickly to minimize the costs of the unplanned breakdowns.
6- Reduce the spare parts inventory by predicting the required equipment or parts in advance.

2.3 Maintenance Types

Knowing the classification or types of maintenance is an essential matter for those who are involved in maintenance activities. It will assist them to make the right decision to choose the appropriate maintenance type for any production assets. The maintenance type of the production assets is selected based on the failure pattern or stops consequences. The literature review revealed that there is a great variation in the terminology of maintenance

types; due to a number of reasons. Trojan and Marçal (2017), state some of these reasons, as follows:

- The concept of maintenance types is not always adapted correctly or well explained, which may cause confusion for others.
- The definition of a particular type differs from author to another.
- Neologism, using translators to translate from foreign languages.

Furthermore, maintenance types can be generally divided into two main actions, which are planned and unplanned maintenance (Veldman et al., 2011; Swanson, 2001; Kothamasu et al., 2006).

1- Planned Maintenance: refers to all procedures of preventive and corrective maintenance that are previously planned in order to be implemented, whereby the equipment is inspected, cleaned, lubricated and all defective parts are repaired or replaced with new ones.

2- Un-planned Maintenance: is also known as reactive maintenance, which means that an immediate action must be taken for any unexpected equipment breakdown or failure to restore the equipment or machine to its original condition; in order to avoid serious consequences such as production losses, damages to the equipment and machines, and workplace risks.

However, the British Standard (2010), classifies the type of maintenance into two fundamental actions: preventive and corrective maintenance, as shown in (Figure 2.1).

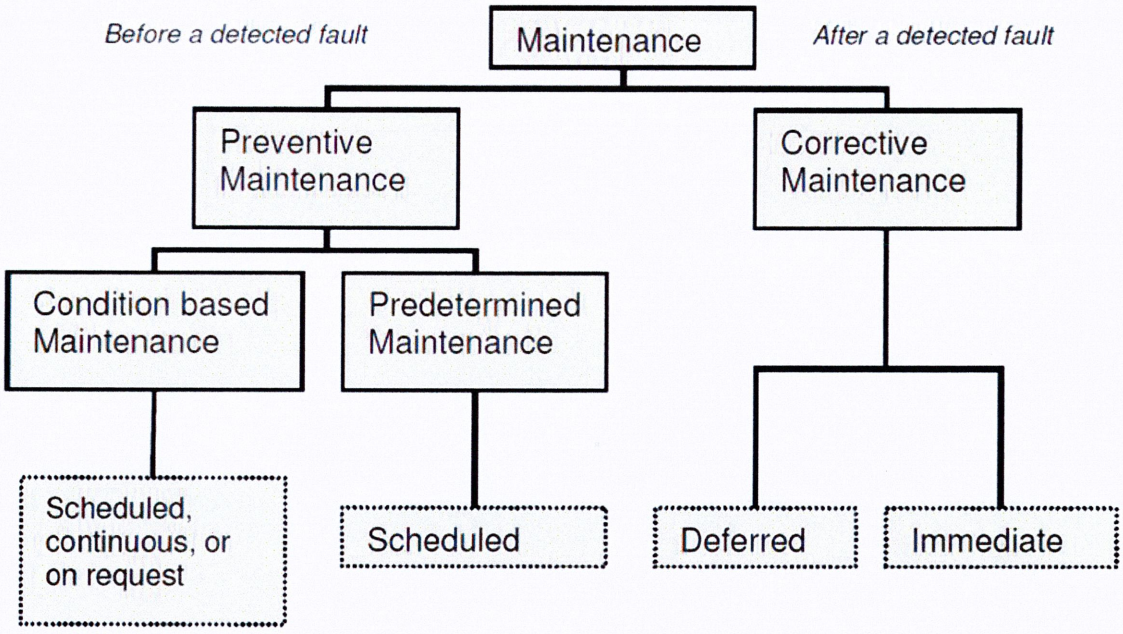


Fig. 2.1: Overview of different maintenance types (BS EN 13306:2010)

1- Preventive Maintenance:

Preventive maintenance aims to prevent sudden breakdowns in the equipment and minimize the severity of the failures. It also increases the useful life of the equipment. It can be achieved by setting a periodic program for cleaning and inspecting the deterioration of all production assets. According to the British standard (BS EN 13306:2010), the Preventive Maintenance is defined as "maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or degradation of the functioning of an item".

- Condition Based Maintenance

  It aims to improve the efficiency of the equipment when its performance indicates a sign of decrease. It also aims to minimize the costs of periodic maintenance actions. The running condition data can be collected visually or through several types of sensors, such as vibration, noise, displacement, etc.; in order to measure the deterioration of the equipment. It may be done on-request, scheduled, or continuous. Once there is a deviation from the norm, a maintenance action plan must be taken to prevent the breakdown. (Pannerrselvam, 2009).

- Predictive Maintenance.

  It is a prediction or forecasting process carried out by condition based maintenance; in order to know and evaluate the status of a significant parameter (BS EN 13306:2017). According to Daley (2008), predictive maintenance helps to perform an action plan before the failure occurred. Therefore, the predictive maintenance aims to reduce the maintenance cost and increase equipment availability (Mobley,2004).

- Predetermined Maintenance

  It is a maintenance carried out through a schedule or predefined interval of time or usage regardless the condition of the assets (BS EN 13306:2017). For example. replacement of the car oil every month or after 10,000 km. It is mainly used for the wearing part of the assets that has a lifetime. It aims to increase the lifetime of the assets and reduce the severity of the breakdown.

2- Corrective Maintenance:

Corrective Maintenance refers to corrective actions like repairing or replacing equipment to fix a specific failure or defect in the parts of the machine. The aim of corrective maintenance is to eliminate the causes of the failure and ensure that the equipment efficiency is returned as designed. The main difference between Corrective Maintenance and Preventive Maintenance is that the equipment failure should occur first then corrective actions must be taken. Tsang (1995), stated that this type of maintenance can lead to serious consequences, such as production losses and high maintenance costs; due to the sudden failures. The corrective maintenance is divided into two subtypes according to how critical the failures are. In other words, some failures require immediate actions, to prevent unacceptable consequences. This type is called Immediate Corrective Maintenance. While, the failure that does not require immediate action to fix is known as Deferred Corrective Maintenance (BS EN 13306:2010).

2.4 Maintenance Strategies

There is an essential need to select a strategy; in order to achieve the targeted objectives which are previously determined by the organization. The Maintenance strategy can be defined as a direction or a road map that is usually taken by the management and experts, to achieve the world-class or the health of the business. According to Bergman and Klefsjö (2010), it is the direction that describes the activities to be performed. The maintenance strategy must be known and followed by everyone in the organization, to

avoid the consequences of any failure. Campbell and Reyes-Picknell (2006), claim that the maintenance activities fall on the run-to-fail strategy when the organization does not work proactive to prevent the failure or its consequences. While, if the organization does not state the strategy clearly, it may require to make some changes at the midway of the journey, causes huge cost, such as losing competitiveness, time, and money. It may also cause confusion for the employees when the strategy is changing frequently. Waeyenbergh and Pintelon (2002), emphasized the importance of reviewing the maintenance strategy periodically; due to environment and business requirement changes. The organization should be flexible in implementing the best practices and applications without changing the main strategy. However, organizations can use mixed strategies if required. Therefore, the selection of a proper strategy is a critical process, which affects the sustainability of the organization.

Nowadays, there are many maintenance concepts used; in order to improve the performance of the maintenance activities. Some of the common strategies are discussed below:

1- Total Productive Maintenance (TPM)

Total Productive Maintenance (TPM) is a maintenance concept developed by Seiiehi Nakajima in Japan. It is one of the oldest concepts that was introduced to integrate the Total Quality Management TQM. TQM is a management concept that is designed to focus on quality control of the products, whereas TPM is designed to focus on improving the effectiveness of maintenance processes. According to Nakajima (1988), TPM is a comprehensive maintenance system, the word "TPM" summarize its meaning with its objectives as:

- Total: means the overall participation of all employees from top management to shop floor employees in all sections, to optimize equipment effectiveness.

- Productive: to achieve the peak of productivity and eliminate the defects, breakdowns, and accidents.

- Maintenance: to ensure equipment and all the assets are properly maintained in perfect condition.

One of the major aims of the TPM is to run the equipment at the maximum efficiency toward participation of all employees in a productive maintenance system; in order to eliminate the equipment losses. These losses consist of the following; (1) Equipment Failure; (2) Set-up and adjustments; (3) Idling and minor stoppage; (4) Reduced speed; (5) Process defects; and (6) Reduced yield (Nakajima, 1988).

However, TPM cannot be applied unless the organization follows its eight different sections, which are known as pillars as shown in figure 2.2. The 5s is the foundation of TPM pillars, and the eight pillars are:



Fig. 2.2 TPM Pillars (Nakajima, 1988)

1- Focused Improvement.
2- Autonomous Maintenance.
3- Planned Maintenance.
4- Quality Maintenance.
5- Training and Education.
6- Early or New Equipment Management.
7- Safety, Health and Environment (SHE).
8- Administrative TPM

5S Practices

The 5s practices play an important role to avoid the delay in preparing the items, which are required for any breakdown. Further, it will make the workplace well- organized and safe to work, by eliminating the risks, such as falls and slips. Hence, it is a valuable program that must be followed by any organization that seeks to improve their maintenance performance.

5S stands for the following five fundamental activities:

1- Sort: To keep the workplace safe and smooth for working, by removing any unnecessary items from the location.
2- Set in order: To arrange the items with an order for easy access and use.
3- Shine: To keep the workplace clean, to identify problem easily.
4- Standardize: Establish clear rules, to ensure that everyone knows his responsibilities of performing, sorting, cleaning, and organizing.
5- Sustain: Train the employees to be aware of how to apply the 5S and its benefits, to become a habit.

Once the organization establishes the TPM foundation successfully, then it will move to build the TPM pillars. If the organization failed to implement the 5s or did not give it enough consideration, this will lead to 5D (defects, delays, dissatisfied customers, declining profits, and demoralized employees) (Wakjira et al., 2012).

The Eight Pillars of TPM

1. Focused Improvement (FI):

Focused improvement means continuous improvement and development of all activities that are affecting the effectiveness of the equipment and overall plant performance. The FI process can be done through different tools like DMAIC (Define, Measure, Analysis, Improve, and Control) tools. Therefore, it will identify and analyze the causes that may lead to the deterioration of the equipment; in order to

make an action to prevent the causes. The major goal of this type is to keep the equipment of the plant always in the optimum condition.

2. Autonomous Maintenance (AM):

It acts as that the operator is the owner of the production assets. As the normal owner behaves when there is minor maintenance that can be handled in his house he will do it without contacting other parties to repair. AM has the same concept, the operator should be trained to act fast when there is a need for any basic maintenance like cleaning, inspection, and lubrication. This concept is a unique feature in TPM when it is compared with the other maintenance programs. The AM aims to let the operation involved in the routine maintenance to achieve the overall equipment effectiveness.

3. Planned Maintenance (PM):

According to Japan Institute of Plant Maintenance 'JIPM' (2010), PM means scheduling the maintenance tasks to have defect-free products and increase the plant availability. PM aims to increase the running time of the equipment and reduce the downtime with the minimum maintenance cost.

4. Quality Maintenance (QM):

The Quality Maintenance means monitoring the quality issues to ensure the machines are producing products with the required standard or products without defects. The JIPM (2010), defines the QM as a condition that can be created in the equipment and then must be controlled to achieve the zero defects stage.

5. Training and Education (TE):

This pillar is concerned with improving the knowledge of all employees in the organization, such as operators, technicians, and management levels .The operators must be trained to a level where they can manage the basic maintenance activities. The technical staff must be trained in higher level skills, such as analytical skills and preventive maintenance skills. They must know how to analyze the problems and find out the root causes of the failures. They also must have preventive maintenance skills to become more competent in performing their work. At the management level, the TPM system considers the management as the core of the organization. They must be trained on the TPM skills in order to be mentors for the junior levels.

6. Early Equipment Management:

It is also known as Maintenance Prevention (MP). In this pillar, the equipment will be inspected to be improved before the normal operation. This ensures achieving the high rate of availability and reliability, before the installation stage. The aim of this pillar is to improve the equipment during the design stage; in order to reduce or eliminate the maintenance costs. It also aims to involve all parties such as operators, maintenance personnel and manufacturers to design high quality equipment.

7. Safety, Health, and Environment (SHE):

This pillar of TPM focuses on achieving a safe workplace to prevent accidents, pollution, and health issues. SHE pillar plays a great role in the attitude and morale of the worker towards the work. When the workplace is a safe environment, the productivity of the workers will dramatically increase and the direct costs of the accidents will decrease.

8. Office or Administrative TPM:

The TPM principle should be spread over the whole organization to ensure that all departments speak one language. Understanding the TPM principle will facilitate and improve the efficiency of the services between the departments. This pillar aims to ensure that the required resources are available once needed to carry out the maintenance activities without any delay. Therefore, the primary goal remains the same which is 'waste elimination'.

2- Reliability Centered Maintenance (RCM)

Reliability-centered maintenance (RCM) is a maintenance concept that was introduced in aviation in the 1960's. It is one of the most effective maintenance philosophies. RCM is a process of analyzing failures that are affecting the equipment operation; in order to determine a schedule for each asset with a proper maintenance method. Moubray (1997), stated that RCM is a method of identifying and ensuring that the assets of the operation are continuously running as expected. NASA (2008), has another definition, RCM is a maintenance strategy which is based on analyzing system functions, failure effects and modes.

The main goals of the RCM are to determine the failure causes and their effects for each critical asset; in order to reduce the Life-Cycle Costs (LCC) and increase the equipment uptime. Moreover, it will increase the awareness of the staff to overcome the risks associated with plant assets. Hence, when RCM is implemented correctly, it will help in achieving a sustained production, so that production capacity is increased. According to Crespo Marquez et al. (2009), it also helps to prevent failures before they occur. Moubray (1997), has summarized the major achievements of RCM, which includes:

- Greater safety and environmental integrity: RCM identifies the causes for each failure that may affect safety and environment before considering the operations.

- Improve operating performance: RCM considers the most suitable maintenance type for each asset to ensure that most effective types are chosen, in order to increase reliability and availability of the assets.

- Greater maintenance cost-effectiveness: RCM helps to focus on the maintenance activities that have a great impact on the plant, in order to ensure the maintenance budget allocated in the most critical assets or the assets.

- Longer equipment life: RCM focuses carefully on the use of co-maintenance technique. In other words, the maintenance will be carried out before the asset failure occurred. This will ensure that the useful life of the assets will be longer.

- Improve the teamwork: RCM provides an easy and common technical language for all maintenance crew and other departments that are linked with maintenance. This facilitates the understanding between the operation and maintenance people, to know what maintenance can or cannot achieve and how it can be achieved.

- Motivate people: RCM helps in improving the understanding of the assets in their operations by people who are participating in the process review. It also provides a wider concept of maintenance problems and solutions which is the "Ownership".

- A comprehensive database: RCM helps to record and document all maintenance requirements for each significant asset that is available. It also provides what maintenance skills that are required for each asset and what spare parts that must be available in stock.

Moubray (1997) stated, that RCM concept consider seven different questions that should be answered. The questions will help in analyzing the organization assets, include the following:

1) What are the functions of the assets and required performance standards of each one?
2) How can the assets fail to meet the required functions?
3) What causes each functional failure?
4) What are the effects when the asset fails?
5) What are the consequences when a failure occurs?

6) What can be done to predict or prevent failures?
7) What can be done if a proper proactive task cannot be used?

In literature, there are multiple ways to implement the RCM process. One of these ways can be summarized in seven steps:

Step 1: Identify the asset for RCM analysis.

Step 2: Define the functions of the system with its limits.

Step 3: Identify the ways that may lead to a system failure (failure mode).

Step 4: Define the causes of each failure.

Step 5: Assess the impact when the asset fails by using different tools and techniques like, Failure Modes and Effects Analysis (FMEA).

Step 6: Select the most effective maintenance tactic for any condition that makes the system fail.

Step 7: Implement the recommended maintenance plan and review it periodically.

Furthermore, Hinchcliffe and Smith (2004), stated that any organization seeking to get the full beneficial outcomes of the RCM program, must assure that RCM is sustained in their organization, as illustrated in figure 2.3.

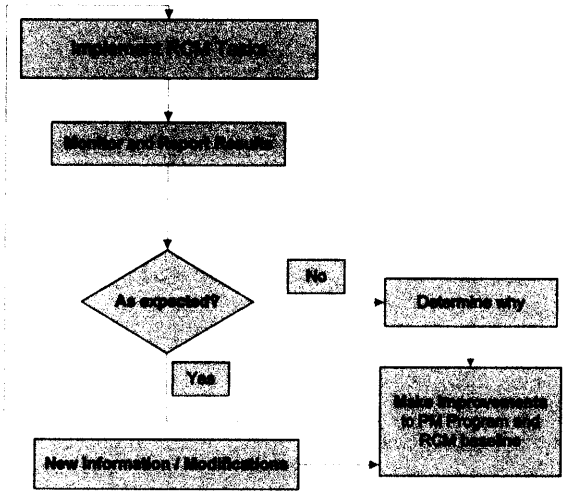


Fig. 2.3: Living the RCM program (Hinchcliffe and Smith, 2004)

Finally, RCM is a concept focused on the asset's reliability by prioritizing them; in order to assign the most effective maintenance plan in terms of financial and labor resources. However, RCM has some disadvantages. It focuses on maintenance personnel rather than the workforce, including operation and management. Moreover, some organizations consider the RCM as an expensive program because it is based mainly on proactive tasks. Waeyenbergh and Pintelon (2002), stated that the RCM is justifiable in critical industries, such as aviation or risky industries. This is due to the fact that, the RCM is often expensive for the general industries, since they focused on economic rather than reliability issues.

2.5 Maintenance Techniques and Tools

The maintenance workforce are constantly seeking solutions to achive an efficient maintenance system. The implementation of such maintenance concept cannot be done fully without adapting certain techniques and tools. The workforce consider the industrial maintenance activities as a very

complicated process. However, once they are trained well on the different maintenance techniques and tools, their mindset will change and the maintenance activities will be more efficient and smoother. Therefore, there is a need to use the tools and techniques that are approved by the maintenance experts; in order to achieve an integrated maintenance framework. Some of these tools and techniques are discussed below.

1- Root Cause Analysis (RCA)

RCA is a systematic process adapted to analyze and trace the real problems, to determine the main reasons or the root causes of the problems or failures. In each failure there is one or more reasons that lead to a deviation from the desired events. The failure word could be in equipment or system, such as a wrong decision, delay in production, repetitive breakdown, quality issue, safety incident, or customer dissatisfaction. The most important goal of the RCA is to plan on how to prevent failures and problems, by identifying and solving the causes. RCA process can be implemend as a group discussion by sharing their ideas in order to identify the main causes of the failurs, and then suggest best solutions. This process is known as brainstorming. Mobley et al. (2008) stated, that the purpose of RCA is to eliminate all factors that negatively affect the safety, environment, equipment reliability, and plant performance. In addition, he indicated that many companies implement the RCA only to find someone to blame.

According to Marquez (2007), the causes could be human, physical, or latent. The human root causes mean human errors that result in a physical root. The physical causes are explaining why the assets fail technically. Finally, the

latent cause means the management deficiencies, such as a lack in the systems or in the procedures that allow the human error to be unchecked.

Therefore, the RCM technique seeks to take the best solutions to be implemented; in order to eliminate the failure from its root.

2- Pareto Chart

The Pareto chart, also known as the 80/20 rule, is one of the seven basic quality control tools. The name of this chart is derived from the name of an Italian civil engineer and economist Vilfredo Pareto, who noticed that 80% of Italy income went to about 20% of the population. The Pareto principle is based on the fact that 80% of the profits comes from 20% of the products. Or, on the contrary, 80% of the problems is produced by 20% of the causes. The aim of the Pareto analysis is to prioritize the problem areas or tasks according to their impacts. This will help in addressing the problems that have the highest impact; in order to be solved first. The Pareto chart is represented as a histogram or series of bars that are arranged in descending order from left to right, depending on the unit of measures, such as frequency of occurrence or total cost. This means that the problems on the left are more significant than the problems on the right. Then a line graph will be used to distinguish, the vital few (20%) problems from the trivial many (80%) problems. Therefore, once the vital few are addressed and solved, then a maximum return can be obtained.

3- Computerized Maintenance Management System (CMMS)

CMMS is computer software designed to assist in managing a wide range of maintenance activities. CMMS is also called Computerized Maintenance Management Information System (CMMIS). It can be used by organizations that look for an effective tool to manage and control the maintenance manpower, spare parts and inventories, maintenance schedules, and maintenance data records. The CMMS can help the maintenance department in tracing and analyzing the maintenance records quickly and accurately. Wireman (2009) stated, that the main function of the CMMS is to enhance the maintenance management and the assets of the organizations. Furthermore, the CMMS can provide many features to facilitate the maintenance management. The CMMS can maintain, sort, and analyze large data, in order to make a right decision. It also can be used to create and schedule the preventive maintenance automatically and send a notification once the inventory reaches a defined point in order to create a purchase requisition.
According to Cato and Mobley (2002), good computerized maintenance management system (CMMS), can produce tangible results in four main areas:

1- Increase the productivity of the manpower.
2- Improve the availability of the equipment.
3- Improve the quality of the product.
4- Improve the inventory control.

2.6 Maintenance Performance Measurement

Many organizations seek continuous improvement, to stay competitive in the market. On that bases, there is an essential need to monitor how the company

is close or far from the assigned objectives. In fact, what cannot be measured cannot be controlled, and what cannot be controlled, cannot be improved. As a result, the Performance Indicators (PIs) are used and it is defined as quantitative indicators, to measure how well the objectives are being achieved (Pritchard et al., 1990).

The PIs are used for many purposes. One purpose is to identify the gaps between the current performance and the desired performance; in order to meet the objectives. Another purpose, is to show the rate of the achievement and highlight the problems that prevent the organization from achieving the required objectives. Accordingly, it will help the maintenance workforce to focus on the areas that have an impact on the organization's performance. Furthermore, the performance measurement can help in selecting the appropriate strategy to achieve the desired goals. In other words, the PIs will help the organizations to ensure that the implemented strategies are leading to the desired achievement and on track. The signal lights of the track are defined as critical success factors or as key performance indicators (KPIs), which are developed as guidelines to reach the desired outcomes. Therefore, the KPIs measure the most important factors to the organization. On the contrary to PIs, which are mostly related to general measures.

Due to the increase in global competition in recent years, the organizations have paid more attention to maintenance; in order to improve the reliability and availability of their equipment. The reliable equipment will help the organization to produce high quality products, deliver the products on time, and provide the customer a product with competitive price. All these factors will assist the organization to gain the stockholders, and customers

satisfaction, which is a way to achieve sustainable competitive advantage to overcome the competitors. Consequently, organizations must ensure the effectiveness and efficiency of the maintenance activities; in order to achieve the desired goals. The Maintenance Performance Indicators (MPIs), will play a key role in monitoring and controlling the Maintenance Performance Measurement (MPM), to be aligned with the organization's objectives and strategies. The MPM is defined as, a group of metrics used to measure the efficiency and effectiveness of maintenance activities and maintenance performance indicators for measuring MPM (Parida and Kumar, 2009). According to Wireman (2005), MPIs are used to measure the effectiveness of maintenance actions that are carried out.

The PIs are commonly classified into two types, which are leading indicators and lagging indicators. The leading indicators are used to monitor how successful the activities are being performed. In other words, leading indicators can be used to predict the future performance. For example, once the PM compliance is low, it is an indication that the chance of asset failures will increase in future. While, if the PM compliance is high, then it is an indication that the asset failure will decrease in the future. On the other hand, the lagging indicators are used to monitor how valuable results or outcomes have been achieved. Both indicators are important to manage the maintenance activities. It should be noted that the leading indicator is more important than lagging indicators, because it allows you to predict and support decision making before falling into an unwanted situation. In addition, establishing a link between leading and lagging indicators is important to monitor and control the maintenance performance, and the indicators must be identified based on the elements of the maintenance function (Muchiri, 2011; Kumar

and Ellingsen, 2000). Selecting good indicators will help in identifying the performance gap, and focusing on the area that has a higher impact on the maintenance performance (Muchiri, 2011).

The leading and lagging performance indicators are described in figure 2.4 (A) and 2.4 (B), along with the world class target (Muchiri, 2011).

Category	Key Performance Indicator	Description	World Class
Work Identification	Percentage of Proactive work %	Man-hours envisaged for proactive work/Total man hours available.	75% - 80%
	Percentage of Reactive work	Man-hours used for reactive work/Total man-hours available.	10% - 15%
	Percentage of Improvement work %	Man-hours used for improvement & modification/Total man -hour available.	5% - 10%
	Work request response rate %	Work requests remaining in 'request' status for <5days/Total work requests	80% of requests
Work Planning	Planning Intensity/Rate %	Planned work / Total work done	95% of all work orders
	Quality of planning %	Percentage of work orders requiring rework due to planning/All WO	< 3% of all WO
	Planning responsiveness %	Percentage of WO in planning status for <5days/ All WO	> 80% of all WO
Work scheduling	Scheduling Intensity %	Scheduled man-hours/ Total available man-hours	> 80% of available man-hours
	Quality of scheduling %	Percentage of WO with delayed execution due to material or man–power	< 2%
	Schedule realization %	WO with scheduled date earlier or equal to late finish date/All WO	> 95% of all WO
Work Execution	Schedule Compliance %	Percentage of wok orders completed in scheduled period before late finish date	>90%
	Mean Time To Repair- MTTR (Hours)	Total Downtime/No. of failures	Context specific
	Manpower Utilization %	Total Hours spent on tasks / Available Hours	> 80%
	Manpower Efficiency %	Time Allocated to Tasks/Time spent on tasks	Manpower Efficiency
	Work order turnover %	No. of completed tasks/ No. of received tasks	Work order turnover
	Backlog size %	No. of overdue tasks/ No. of received tasks	Backlog size
	Quality of Execution (Rework) %	Percentage of maintenance work requiring rework	< 3%

Fig. 2.4 (A): Leading performance indicators (Muchiri, 2011)

Category	Key Performance Indicator	Description
Measurement of Equipment Performance	No. of failures	Number of failures classified by their consequences; operational, non-operational, safety...
	Failure per breakdown frequency	No. of failures per unit time (A measure of reliability)
	Mean time between failure-MTBF (Hours)	Mean time between failure- a measure of reliability
	Availability %	MTBF/(MTBF + MTTR)= uptime/ (uptime + downtime)
	Overall equipment effectiveness (OEE) %	Availability * Performance rate* Quality
Measures of cost	Direct maintenance cost $	Total corrective and preventive cost
	Breakdown severity %	Breakdowns cost / Direct maintenance cost
	Maintenance intensity	% of maintenance cost per unit of products produced in a period
	% of maintenance cost component over manufacturing cost	Maintenance cost / Total manufacturing cost
	ERV (Equipment replacement value)	Maintenance cost / New condition value
	Maintenance stock turnover	The ratio of cost of materials used from stock within a period
	Percentage cost of personnel	Staff cost/total maintenance cost
	Percentage of cost subcontractors	Expenditure of subcontracting / Total maintenance cost
	Percentage cost of supplies	Cost of supplies / Total maintenance cost

Fig. 2.5 (B): Lagging performance indicators (Muchiri, 2011)

2.7 Maintenance Investment

Many organizations strive to improve their plant reliability and availability to be more competitive, especially with the increased global interactions over the world. They seek by all means to improve their competitiveness, by implementing the best maintenance practices. Therefore, implementing best maintenance practices play an important role, which affects the sustainability of the organizations.

The old-age management perception about "maintenance" has a negative concept. They usually link maintenance terms to a broken equipment or machine which needs to be repaired or replaced. They also consider maintenance activities as a loss of money and time.

In contrast, Today's concepts of maintenance have been dramatically changed, to be an essential function needed in most organizations. This change led to an increase in organizations awareness to invest more in maintenance activities. The investment could be in people, technology, and training. The reflection of this investment or the Return on Investment (ROI) will be as production revenue, by increasing the capacity and quality of the production. For example, ROI is also considered when organizations are investing in predictive maintenance, to eliminate the cost of doing preventive or corrective tasks. This reduction is translated as additional profit. An empirical study conducted in Belgium and the Netherlands on some selected industries done by Pinjala et al. (2006), found that the quality competitors with advanced production technology were allocating more budgets for maintenance. In comparison with others, they have better maintenance systems, such as proactive policies and planning that assisted them to take the required actions before the occurrence of any failure.

Therefore, It is crucial to have an explicit maintenance management framework for any organization seeking additional profits from the investment on maintenance.

2.8 Maintenance Management Framework (MMF)

Many organizations seek to implement the best maintenance framework that is described in literature, or copy a framework from another organization. However, this thing is not always right, since each organization has its own unique situations and factors. Therefore, each organization must develop or tailor an appropriate maintenance framework according to what is on hand. Eventually preventing the organization from any difficulty while implementing the available concepts.

Accordingly, this section will describe the most popular maintenance frameworks available; in order to create an appropriate maintenance framework that will lead to improving the IMS performance.

1- Maintenance Management Framework (MMF) - 1:

Campbell (1995), developed a structured maintenance management framework with four levels, as shown in figure 2.5. The first level starts with developing a maintenance strategy for each critical asset. At the same time, an association of human resources is required to produce the needed in case of any cultural change. The second level focuses on observing and controls the performance of each asset, to ensure the desired function is achieved along with the lifetime of the asset. This can be achieved through implementation of a measurement system in order to gather the performance metrics, to plan and schedule the maintenance activities and eight tactics. The third level adopts RCM and TPM concepts for continuous improvements. The fourth level suggests using maintenance re-engineering for quantum leap improvement.

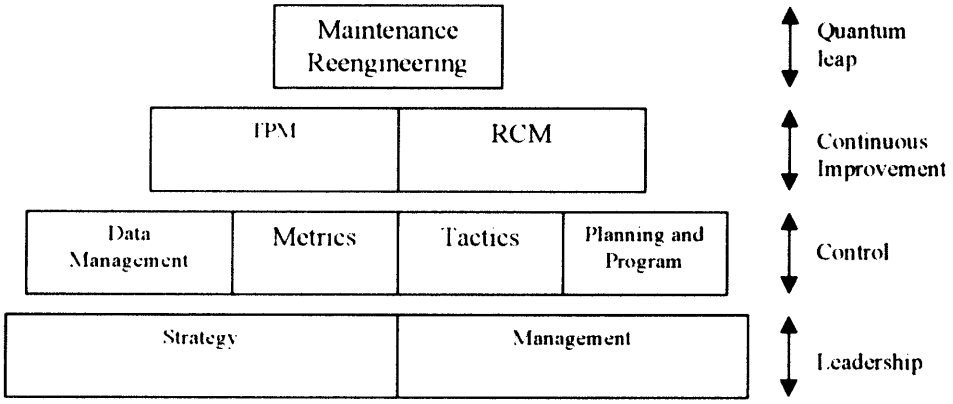


Fig. 2.5: Maintenance Management Framework (Campbell, 1995)

2- MMF (2):

Waeyenbergh and Pintelon (2002) provide guidelines for developing a customized maintenance plan. The authors stated that each company should have a unique maintenance plan for two reasons. First reason, the relevant factors are not identical in all companies. Second reason, due to the rapid increase in the technologies of the industrial systems. The maintenance plans will be reviewed periodically; in order to ensure the changes in systems and the environment are considered in the plans.

The authors emphasized on the data which is considered one of the most important factors in the maintenance plan development. There are two levels of data. The first level data are the system installation records, while the second level data are the records of the normal work. Data is important in all maintenance plan stages. For example, with the help of the data, the asset failure pattern can be easily identified so that an effective action can be planned.

The goal of the framework was to develop a total maintenance plan for different plants and for different installations. The proposed framework consists of six steps, as shown in figure 2.6.

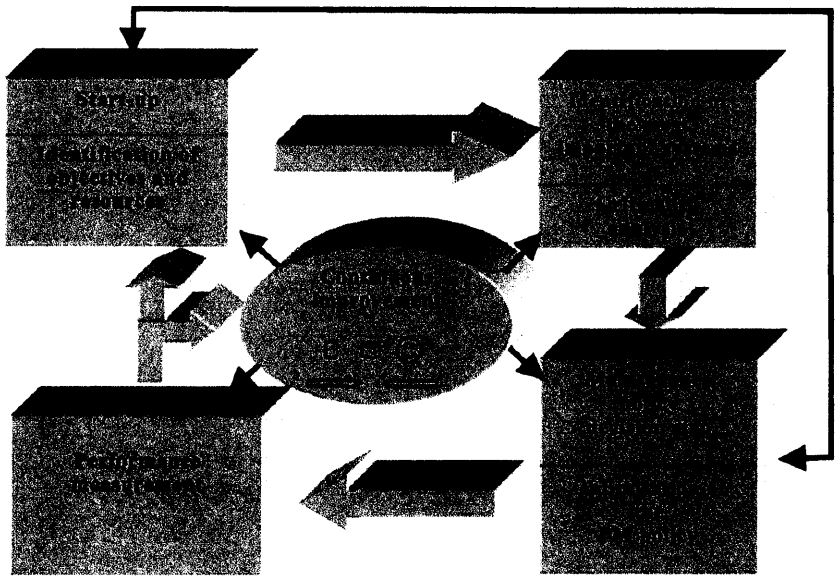


Fig. 2.6: The proposed framework (Waeyenbergh and Pintelon, 2002)

3- MMF (3):

Wireman (2005), designed a maintenance framework that consists of 15 blocks. These blocks are distributed through five levels, as shown in figure 2.7. He believes that before moving to execute the CMMS, system of the work order, provision of spare and employee training; a fundamental program should be implemented that is preventive maintenance. Prior to TPM implementation and financial optimization, RCM, operation involvement, and predictive maintenance must be executed. The fifth level addresses the process of continuous improvements. The aim of this framework is to provide

step by step activities to improve all functions of the maintenance management.

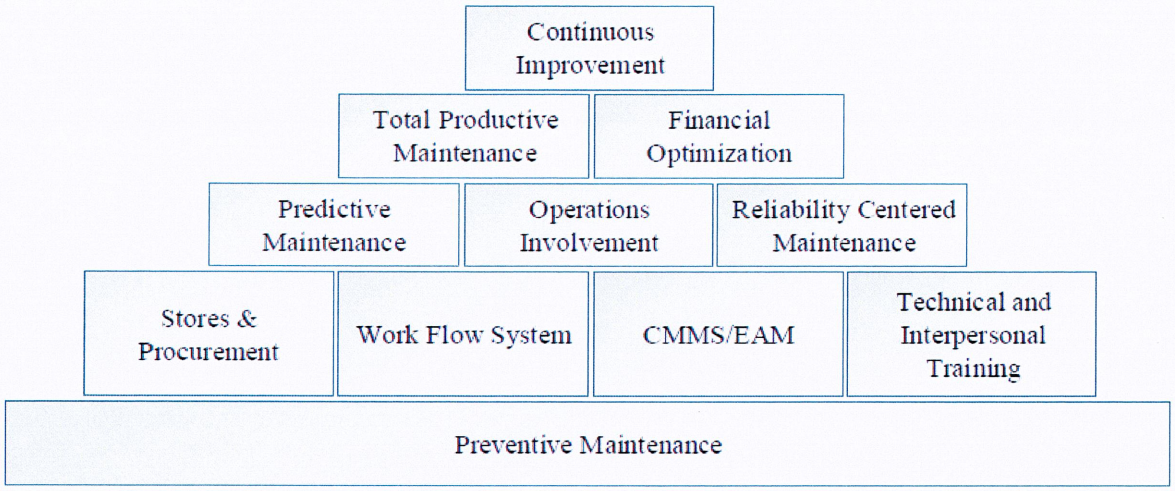


Fig. 2.7: Maintenance Framework (Wireman, 2005)

4- MMF (4):.

An eight phase framework was developed by Crespo Márquez et al. (2009), to increase the efficiency and effectiveness of maintenance management. As illustrated in figure 2.8, each phase focuses on a key decision area to balance the requirement of an optimal maintenance management; in order to ensure that the all goals and objectives of the business are achieved.

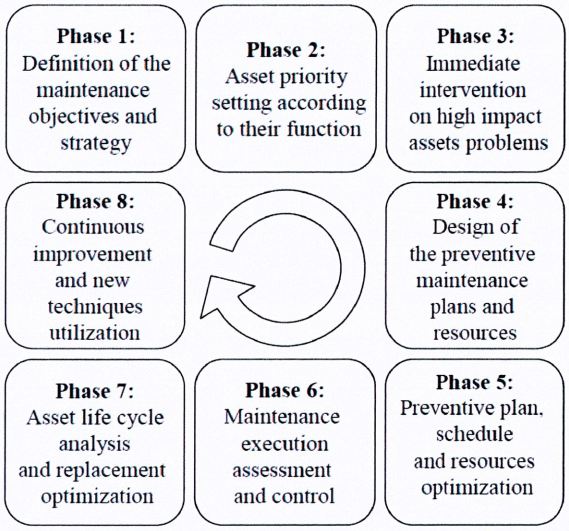


Fig. 2.8: Maintenance Framework (Crespo Márquez et al., 2009)

- Phase 1. Identify the maintenance objectives and the KPIs. In order to ensure the consistency of the business strategy with the operational objectives, the objectives and KPIs of the maintenance must be clearly identified. The authors used a balanced scorecard and then specified a set of KPIs to monitor the strategic business objectives.

- Phase 2. Prioritize the asset and define a proper maintenance strategy. In this phase, the authors emphasized on the importance of asset prioritization in order to facilitate the maintenance action selection that lead to business target achievement. The suggested technique that can be used to prioritize the asset, is the risk assessment method. The advantages of asset prioritization are that an effective maintenance action will be selected and the indirect maintenance costs will be reduced.

- Phase 3. Root Cause Failure Analysis (RCFA). The authors used RCFA to intervene in the high impact weak points.

- Phase 4. System preventive plan designing. It is required to know the function of the system before starting the design of the PM plans. By studying the system's function, the failure behavior can be identified. Once the system failures are known, an effective PM plan can be set based on safety and economy to prevent the causes of the failures. The authors suggested Root Cause Analysis (RCA) method to be used which will allow to detect and eliminate the causes of failures before they occur.

- Phase 5. PM plans, schedules, and resource optimization. Once the initial PM plans are designed and the required resources identified, the next step is to optimize the PM planning and scheduling, to enhance the efficiency and effectiveness of the maintenance policies. The optimization model plan will vary on the time horizon of the analysis. In a long- term model, the maintenance planning limits, provisioning of spare parts, and determination of maintenance interval will be addressed. In the mid-term model, maintenance activities of long plant shutdown will be addressed, while in the short model the resources allocation and control will be addressed.

- Phase 6. Assess the maintenance execution and control. Once the maintenance activities are planned and scheduled, it has to be evaluated to be continuously controlled, using key maintenance performance

indicators. This will ensure that the required level of performance is aligned towards the business target.

- Phase 7. Life cycle analysis for the assets. Using life cycle analysis to calculate the cost of the asset for the entire asset life span. The life cycle cost analysis depends on the reliability analysis values like cost of spars, failure rate, repair time, and cost of components. The analysis is important when making a decision to keep or sell the asset.

- Phase 8. Continuous improvement. The last phase is about building a continuous improvement culture, by utilizing the latest technologies and techniques in the area that has a higher effect on the result. One of the most important technologies is E- maintenance, which can be used to monitor and control the resources and services efficiently. In addition, the authors emphasized on the importance of maintenance person's involvement, which is considered as a critical factor in the maintenance improvement process. Total Productive Maintenance (TPM) is suggested as a way for the maintenance involvement and continuous improvement.

5- MMF (5):

Faccio et al. (2014), has proposed a quantitative framework in order to help in developing optimal maintenance policies. The framework is developed using cost models, such as labor, missing manufacturing cost, spare part, and other items of indirect costs. The authors focus on failure-based maintenance since it is the most common approach applied in industries. The authors also

have extended the approach to include predictive maintenance policies such as Condition Based Maintenance (CBM). The framework consists of three phases, including equipment analysis, data analysis and collection, and decision making process as shown in figure. 2.9.

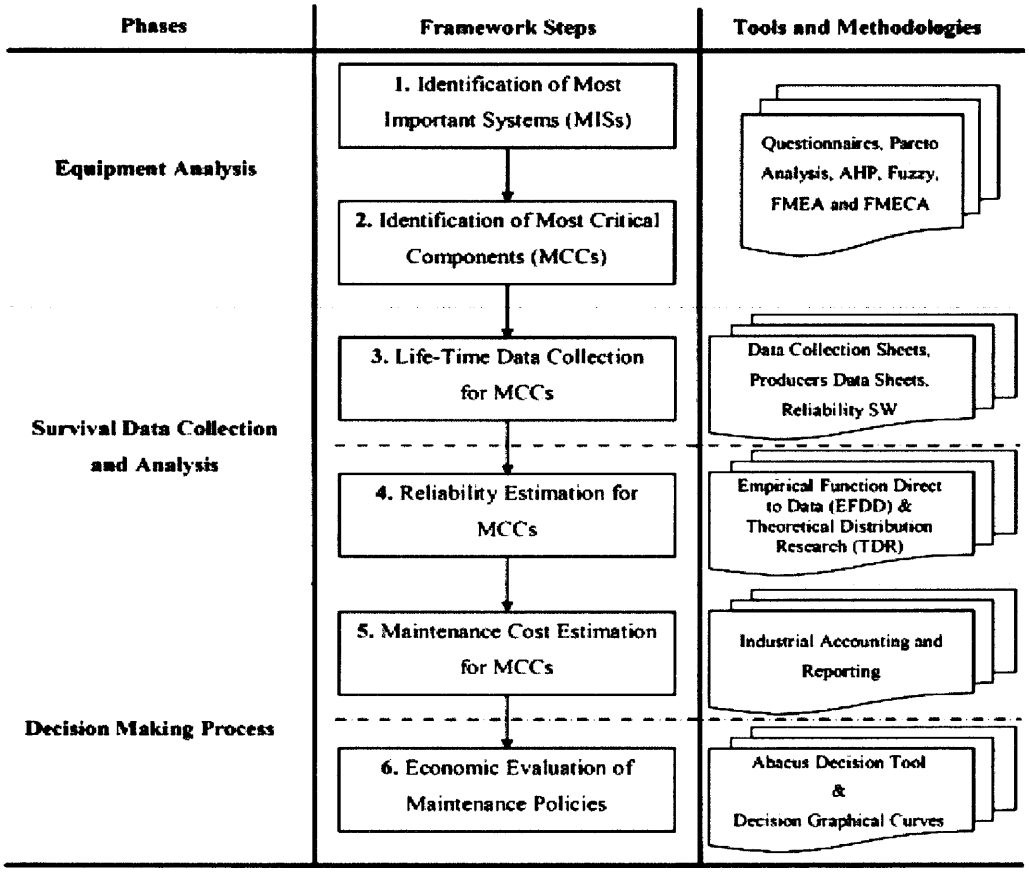


Fig. 2.9: Maintenance Framework (Faccio et al., 2014)

Chapter Three

Research Methodology

3.1 Introduction

3.2 Research Design

3.3 Research Purpose

3.4 Research Strategy

3.5 Research Approach

3.6 Research Validity and Relaibilty

3.7 Research framework

3.8 Data Collection Tools and Techniques

3.1 Introduction

This chapter presents the methods and techniques adapted to achieve the research objectives. It acts as a guideline plan for the researcher to follow during the research study execution. It begins with formulating the design and type of research study, followed by research strategy, approach, and framework. Finally, it investigates the adopted tools and techniques applied to collect and analyze the data of the research study.

3.2 Research Design

The research design is the overall plan or framework used to address how the research questions will be answered clearly and effectively. Thereby, achieving the objectives of the research. In other words, it is a set of procedures or methods that involve data collection, and analysis, for the purpose of explaining the results and publish the findings (Myers, 2008). There are different types of research design. These types are classified according to the area and purpose of the study. Robson (2002), stated that the research design has three possible forms: Exploratory, Explanatory and Descriptive.

3.3 Research Purpose

Exploratory Research

The exploratory research is conducted to explore a problem that is little known or unclear phenomena (Saunders et al., 2019). It is the most useful design; it

aims to increase the understanding of the problem or phenomena, by referring to the experts in the subject without giving final evidence. It also helps to give a general picture about the situation which needs to be developed. Exploratory questions that are used for the data collection often begin with "What" or "How". It has an advantage that enables the researcher to be flexible with the results of the obtained data which may affect the direction of the research.

Descriptive Research

From its name which is derived from describe, it is used to describe or explain an event or situation using 'What exists' rather than answering 'Why' questions. It is usually processed by explanatory research which helps to gather more information about the research study. It aims to clarify a present phenomenon or condition; in order to formulate a better understanding of the phenomena. It also aims to improve the existing practices, behaviors, or the environment, by gathering information about the 'root causes' of the problems. The common methods used in descriptive research are observational method, case study method, and survey research.

Explanatory Research

It is also known as 'analytical or causal' which explains a problem or a phenomena to discover the relationship between two or more variables of the study. In other words, It focuses on studying the aspects of the research questions in detail, to greatly help the researcher, to reach beneficial conclusions. The explanatory aims to identify the reasons or 'Why' factors, by giving evidence to support the research problem or phenomena. According

to Yin (1994), the explanatory research is when the study focuses on cause-effect relationships.

As mentioned earlier, the main objectives of this research is to explain the existing practices of IMS, and to identify the factors that are affecting their performance. It also, aims to develop a conceptual framework to find out the relationship between the factors and performance improvement. To achieve this, the research questions are presented by 'What exists', 'How' and 'Why'. Therefore, it is obvious that the purpose of this study is descriptive and explanatory in perspective.

3.4 Research Strategy

It is considered to be a plan of how the researcher will answer the research questions. It is simply a technique that will be used by the researcher to achieve the goal of the research. Saunders et al. (2019), state that there are different strategies that can be used. These strategies include the following:

Experiment

Experiment or laboratory-based requires the researchers to notify the change between an independent variable dependent variables. It uses hypotheses to predict the relationship that may exist between the variables. The experiment strategy is considered to be experimentory and exploratory research, because it attempts to answer 'What', 'Why', and 'How' questions.

Survey

It is one of the most frequent strategies used in quantitative research. It is an organized strategy that uses questionnaires, structured interviews or structured observations to collect data. It makes the process of the data collection easier and economical from a huge population. The survey strategy is considered to be exploratory and descriptive research, because it attempts to answer 'what', 'where', 'who', 'how much', and 'how many' questions.

Case Study

The case study strategy allows the researcher to study a situation or phenomena in-depth within its real-world setting (Yin, 2014). The main goal of this strategy is to build an intensive knowledge about the case. The case may refer to an individual, group, or organization. The case study strategy attempts to answer 'how' and 'why' questions; in order to achieve a richly detailed understanding of the case. Yin (2014), states that this strategy can be used for exploratory, descriptive, and explanatory research.

Action Research

The action research strategy has a variety of interpretations in literature. However, there is a tendency to define it as an emergent method, which seeks to improve solutions to the organizational problems; by collaboration between the researcher and the organization. The purpose of this strategy is to support the organizations to overcome the issues. It involves several stages to achieve

practical outcomes. Each stage includes a process of identifying issues, planning action, and evaluating taken actions.

Narrative Inquiry

In this strategy the researcher decides to be a listener to hear a story from the narrator (participant); in order to be interpreted and analyzed. The sequence of events aids and enriches the researcher's understanding, which makes it easy to compare and contrast events. Narrative inquiry is generally associated with a very small number of participants; due to the large amount of data and time-consuming process particularly in the analysis stage.

The strategy which is used in this research is a case study. It has been chosen to examine and support the results of the literature. This study will evaluate the present maintenance practices; in order to develop a conceptual framework to improve the IMS performance of the Carbon Department in ALBA.

3.5 Research Approach

There are three essential approaches utilized in conducting any research such as qualitative, quantitative, and mixed methods. These methods are classified according to the data that is gathered from the respondents as the answers of the research questions.

Qualitative research: in this type, the research data will be collected and analyzed in non-numerical format. It is often used to help the researcher to look at the problem deeply. According to Brady (2015), the qualitative method

aims to develop a deep understanding of the topic or problems. There are common methods used to collect qualitative data, such as unstructured interviews or open-ended questionnaires.

Quantitative research: It is based on numerical and statistical data that are used to generate a relationship between the causes and the problems. In other words, the quantitative method depends on numerical data in exploring, explaining, or describing a phenomena or problem. The quantitative method is more highly structured than the qualitative method. The researcher applies various techniques to collect the quantitative data, including structured interviews, closed-ended questionnaires, and surveys.

Mixed approach: recently, most of the studies are using this type of methods. It depends on both qualitative and quantitative methods, so that the study will take the advantages of both methods. It aims to help the researcher in answering the research question widely, and to have more evidence to achieve an effective conclusion.

Accordingly, this research study will utilize the mixed approach; in order to answer the research questions. A questionnaire will be adapted to find out the map of the present practices; in order to understand the existing maintenance management system. Furthermore, to identify the factors that influence the performance of IMS, the data will be obtained from semi-structured interviews, which are the qualitative data.

3.6 Research Validity and Reliability

The research is called valid when it measures what it claims to measure. According to Yin (1994), the validity of any research must be maximized to ensure that the quality of the collected data reflects the studied phenomenon. Moreover, the research is called reliable when the data collection techniques reproduce similar findings, if repeated in the same circumstances by another researcher.

Accordingly, validity and reliability were major concerns in this research. Therefore, a combination of qualitative and quantitative approaches were used in order to increase the validity and reliability of the study. Yin (2014), stated that a mixed method helps the researcher to answer complex research questions and accomplish validity and reliability of the study. Patton (2002), emphasized that using two or more tools in collecting the research data gives higher credibility and strength to the study.

3.7 Research Framework

This framework provides sufficient details for each specific step which will be followed in this research. The following steps summarize the methodology of this research study:

Step 1: Formulating the research problems and objectives.

Step 2: Reviewing the literature to have an intensive knowledge of maintenance management practices, and identifying the factors that influence the maintenance performance.

Step 3: Defining the framework of the research, and then select the appropriate case studies to be investigated, and prepare the data collection tools.

Step 4: Collecting the historical data from the case studies, then analyze them to identify the existing gaps.

Step 5: Developing a new maintenance management framework to improve the IMS performance by solving the existing issues.

Step 6: Providing a conclusion and recommendation, according to the result of the study.

The steps for the Research Framework are depicted in Fig. 3.1

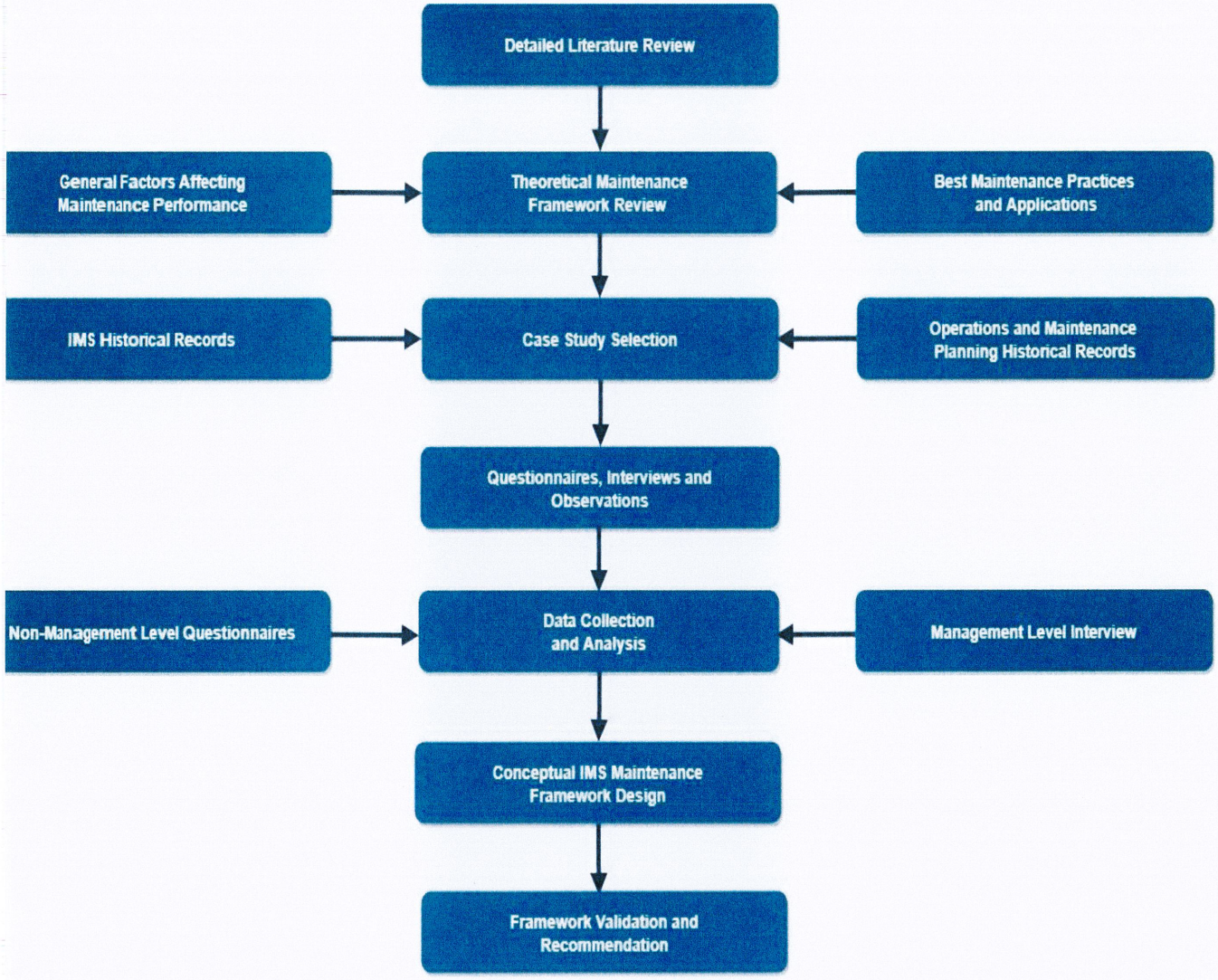


Fig. 3.1: Research framework

3.8 Data Collection Tools and Techniques

In order to ensure that all objectives of the research have been covered correctly, both secondary and primary data will be utilized. According to Churchill (1999), the secondary data should not be bypassed, but rather be explored, unless there is no data about the subject matter, then proceed to the

primary data. The purpose of the secondary data is to answer the research questions by reviewing previous studies, journals, books and online databases. This research will explore the benefits of implementing the maintenance management techniques on productivity and quality through literature review. It also will shed the light on the best maintenance practices and examine the key factors that affect the performance of maintenance within organizations.

On the other hand, the primary data refers to the data collected by the researcher himself for the first time; in order to be analyzed to answer the question of the research. Saunders et al., (2019), stated that there are several techniques that assist the researcher to collect the data, and the main methods are observations, interviews, questionnaires, and surveys.

3.8.1 Observations

It is recording the behavior of people; in order to be interpreted and analyzed in a systematic way. The types of observations are:

Participant observation: the researcher plays the role of an effective observer through participating in the social lives, as a member of the group or the organization. The researcher will fully share the activities within the group, which makes him aware of their perceptions and actions.Therefore, he is an observant and a participant.

Structured observation: it is a systematic technique, in which the data will be collected in a structured way and procedural manner. In this type, it does not need the researcher to be involved directly with the participants to collect

the data. It assists the researcher collect the data that cannot be collected using surveys and interviews.

3.8.2 Interviews:

It can be defined as an oral conversation between the researcher and person or people with a purpose of obtaining information related to the research questions and objectives. The interviews can be classified into three different types as follow:

Structured interview: it is also known as standardized interview, in which a list of questions will be prepared by the researcher before the interview. Then, the same questions will be asked in all interviews and often with the same order. In this type, the questions could be open-ended or closed-ended. It is commonly used in survey research.

Semi-structured interview: it is also called a non-standardized interview, in which a few questions will be predetermined as a theme or guide of the interview. The order of the questions may vary from interview to another. The researcher can change the sequence of questions according to the flow of the discussion. Moreover, the researcher may add new questions during the interview, if required to collect more information about the area of interest. This type is mostly used in exploratory research, where it acts as the primary stage for the in-depth studies.

Unstructured interview: It is also known as in-directive interview. In this type, the questions that will be asked in the interview are not prepared in

advance. Instead, the researcher will ask questions that depend on the flow of the conversation to have a general knowledge about a topic. It means that the questions that arise by the researcher are different in each interview.This type is mostly used in exploratory research, where it acts as the primary stage for the in-depth studies.

3.8.3 Questionnaire

Questionnaire is a tool used by researchers to obtain data from a group of respondents using a form that consists of a list of questions. It is considered as the highest method in collecting data, because it is inexpensive and does not need much effort. However, the questionnaire designing is critical. Therefore, the researchers must pay special attention during the designing stage. The questions have to be clear, accurate, and concise as much as possible.

Furthermore, the questionnaire and structured interview are very similar. The main difference between them is that in the questionnaire method, the respondents must read and answer the questions by themselves, which is without the researcher's presence.

According to Saunders et al. (2016), the questionnaire can be classified into two types, self- administered and interviewer- administered.

Self-administrated: in which the questions are usually completed by the interviewees themselves. The way communicating between the researchers. and interviewees is by hand, post, or e-mail.

Interviewer-administered: in this type of questionnaires, the researcher will collect the data from the respondents, through structured interviews or by phone.

These two types can be more classified according to the design of questions and answers as follows:

1. Closed-ended questionnaire: The respondents are restricted within their answers by the given options from the researcher, such as multiple choice questions, or simply they answer 'Yes" or "No" questions. The main advantage of this type of questionnaire is that the researcher will convert the collected answers to statistical data and percentage.

2. Open-ended questionnaire: This questionnaire allows the respondents to answer the questions in detail by explaining freely his/her thoughts. Generally, this type is used when there is not enough data on the studied topic. Therefore, it will seek for an improvement from the feedback or suggestions from the respondents.

3. Mixed questionnaire: in this type of questionnaire, the researcher will use a combination of both open and closed ended questionnaires. It may help researchers when there is doubt or uncertainty about the possible answers. Accordingly, the respondent will have an option to answer in his/her way, or choosing among the given answers.

In this study, several methods have been used to collect the research primary data. The first method was mixed questionnaire. The questionnaire surveys

were distributed to all IMS non-management staff. The purpose of the questionnaire was to measure the present maintenance practices; in order to be evaluated according to the best maintenance actions. The second method was semi-structured interviews. The interviews were conducted with the managerial level, such as IMS supervisor, head of maintenance and planning section. The aim of the interviews were to investigate and define the factors that influence the IMS performance. The third method was participant observation; as the researcher is part of the case study organization. The aim behind this method was to compare the answers of the questionnaire with the present practices of IMS maintenance and other related activities.

Chapter Four

Instrument Maintenance Section (IMS) Pilot Research Study

4.1 Introduction

4.2 Aluminum Industry

4.3 Aluminum Bahrain Overview

4.4 ALBA Strategic Plan

4.5 A Four Year ALBA Production and Safety Review

4.6 ALBA Production Process

4.7 Carbon Department Structure

4.8 Carbon Maintenance Department

4.9 Instrument Maintenance Section (IMS) of Carbon Department

4.10 Kiln Plant Productions

4.1 Introduction

The aluminum industry in the Kingdom of Bahrain is the second largest income after petroleum production. It plays a key role in building and developing the national economy. Maintenance costs are considered a large part of the industry's expenses, which directly affects the profit of the company and then reflects on the Bahrain Gross Domestic Product (GDP). Therefore, all maintenance departments of ALBA strive to implement the best tools and techniques that are necessary to achieve their objectives at the minimum time and cost.

According to the significant impact of ALBA company on the overall economy of Bahrain. ALBA has been selected as the case of this research. The research will shed light on the Instrument Maintenance Section (IMS), at the Carbon department. It will study and analyze the current maintenance management practices and its direct and indirect impact on the stability of the production process. At the end of this study, a maintenance management framework will be proposed to overcome the difficulties faced by the IMS; in order to enhance the performance of the employees and ensure the continuity and quality of the production process.

4.2 Aluminum Industry

Aluminum is one of the most abundant metals found in the Earth's crust. It is not a natural element that can be extracted directly by digging into the earth. It is obtained mostly from an ore called bauxite, which consists of the primary

material of aluminum oxide or alumina. Then through a chemical reaction using electrolysis process the liquid aluminum is produced.

Aluminum attracts lots of end-users; due to its multiple characteristics. For example, aluminum is light, non-toxicity, electrical and thermal conductive, and corrosion resistance. However, the aluminum as a product is currently challenged with different products that can replace the aluminum for the end-users, such as magnesium, steel, and plastic. This creates a huge amount of pressure on the aluminum producers to reduce the prices of the aluminum as much as possible; in order to attract the end-users. Therefore, the aluminum producers seek to reduce the cost of their production. Reducing the production cost and improving productivity are the main concerns for the aluminum smelters to remain competitive in the market. Furthermore, the competition between the aluminum smelters has increased and arrived to the capacity and the quality of the products. This matter has also a potentially high effect on the aluminum producers to control their costs, since the aluminum price is set in London Metal Exchange (LME) according to the supply-demand balance.

The maintenance management plays a major role on the profit of the smelters. Where it can reduce the repetitive breakdown and their severity, improve the product's quality, and improve the equipment reliability. According to Ndjebayi (2017), the maintenance and overhead have a cost equal to 8% from the total production cost, as illustrated in figure 4.1. Thus, it requires significant attention from the producers, to increase the Rate of Return (ROR).

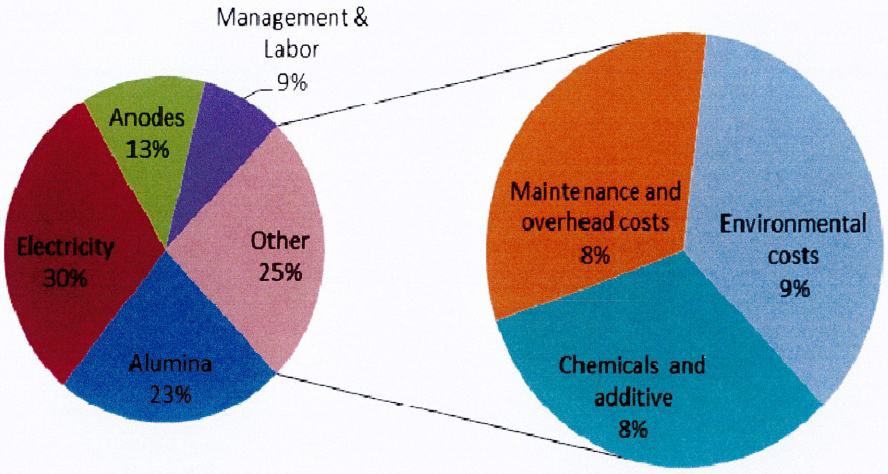


Fig. 4.1: Aluminum production cost distribution (Ndjebayi, 2017)

4.3 Aluminum Bahrain Overview

The Aluminum Bahrain Company is widely known as ALBA. It was established in 1968, and officially started its operations on 11th of May 1971. It was the first aluminum smelter in the Middle East and the first non-oil company established in Bahrain. ALBA begun its operations with 120,000 tons per annum. Today, it became the largest single-site smelter outside China after line 6 expansion project. This expansion project helpped the company to increase its total production by half million metric ton per annum (mtpa). Therefore, the production target of 2020 is 1,540,000 mtpa. The primary products of ALBA are standard ingots, foundry alloys, rolling slabs, extrusion billets and liquid metal. Figure 4.2, shows the total sales of each product in 2019. ALBA's products are used in several industries such as transportation, packaging, construction, etc. The company also produces other types of products, such as anodes, water, calcined coke and electricity.

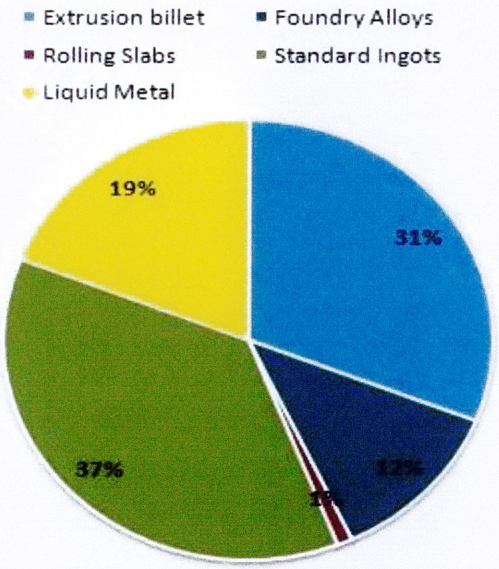


Fig. 4.2: ALBA Products in 2019

ALBA's products are distributed over the world and the top five consumers based on regions are shown in figure 4.3.

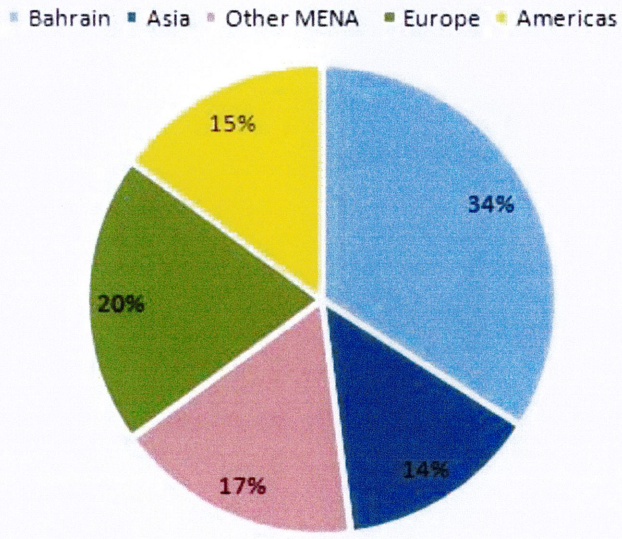


Fig. 4.3: Total distributed products of ALBA in 2019

ALBA's total number of employees exceeded 3000 employees, and about 83% are Bahrainis. The shareholders are Bahrain Mumtalakat Holding Company with a share of 69.38%, followed by SABIC Investment Company with a share of 20.62%, and the remaining 10% of shares belongs to the general public.

Safety, health and work environment factors are considered as the highest priority for ALBA. ALBA believes that these factors are the productivity drivers. Hence, it focuses on building and developing a strong safety culture in and outside the company; through safety campaigns over the year and each campaign has a theme with massive valuable messages. ALBA has achieved in 2019 a safety historical record, which it crossed 15 million working hours without any single Lost Time Injury (LTI), Table 4.1 presents ALBA's production and safety review (2016-2019).

4.4 ALBA Strategic Plan

ALBA has identified three major Key Performance Areas (KPAs) as a strategic plan to achieve the company's vision and mission. The first major KPA is related to social responsibilities which include four perspectives; namely: safety, health care, environment, and people development. The second major KPA is about profitable growth, which focuses on the production capacity, sales, the customer's perception, and innovation. The third KPA that has a major contribution in achieving ALBA's goal is the global competitiveness which includes two perspectives; namely: cost

competitiveness, and the quality of the products. Table 4.1 shows some of the KPI formulations for ALBA's goals with the Key Performance Area (KPA).

Table (4.1): KPI formulation of ALBA's Key Performance Area

KPI Formulation					
Goal/ Strategic Objective	KPA	Leading Performance Indicator		Lagging Performance Indicator	
		Primary Indicator	Measure	Secondary Indicator	Measure
Knowledge development	People development/Training	Yellow, Green, and Black Belt/ Other training	Number of training conducted	Projects (YB,GB,BB, Kizen, and other improvement initiatives	Number of projects
			Number of people trained	Engagement	Number of trainees engaged
Titan (Cost reduction)	Financial/ cost comptitvness	NA	NA	Cost saving	Cost/Money saved
Enabling safety	SHE	5S implementation	Number of departments implement 5S	5S sustains	Number of department 5S sustained
Process knowledge improvement (production, maintenance, administrative, and safety)	Process improvement/innovation	Specific module/ tools like FMEA, Fish bone, and 5 Why.	Number of training conducted	Small projects/ other improvement initiatives	Number of projects
			Number of people trained	Engagement	Number of trainees engaged
Good suggestion (managing innovation/ creative)	People development/ innovation	On time evaluation of good suggestion	Number of evaluations	NA	NA

4.5 A Four Year ALBA Production and Safety Review

Table (4.2): ALBA Production and Safety Review 2016-2019 (ALBA website)

ALBA Products					
Area	2016	2017	2018	2019	Trend
Total Metal Productions (mtpa)	971,420	981,016	1,011,101	1,350,326	∧
Total Metal Sales (BD'000')	669,760	857,762	911,317	1,029,378	∧
Total Profits (BD'000')	48,390	92,457	59,755	5,379	∨
ALBA Safety					
Fatalities (Employees& Contractors)	0	0	0	0	=
Lost Time Injuries (LTI)	3	6	3	0	∨
Total Recordable Injuries (TRI)	64	57	32	6	∨

4.6 ALBA Production Process

ALBA consists of six main departments associated directly with the production process. Each department is a group of many plants. The main departments are calciner, carbon, reduction, cast-house and power as shown in figure 4.4.

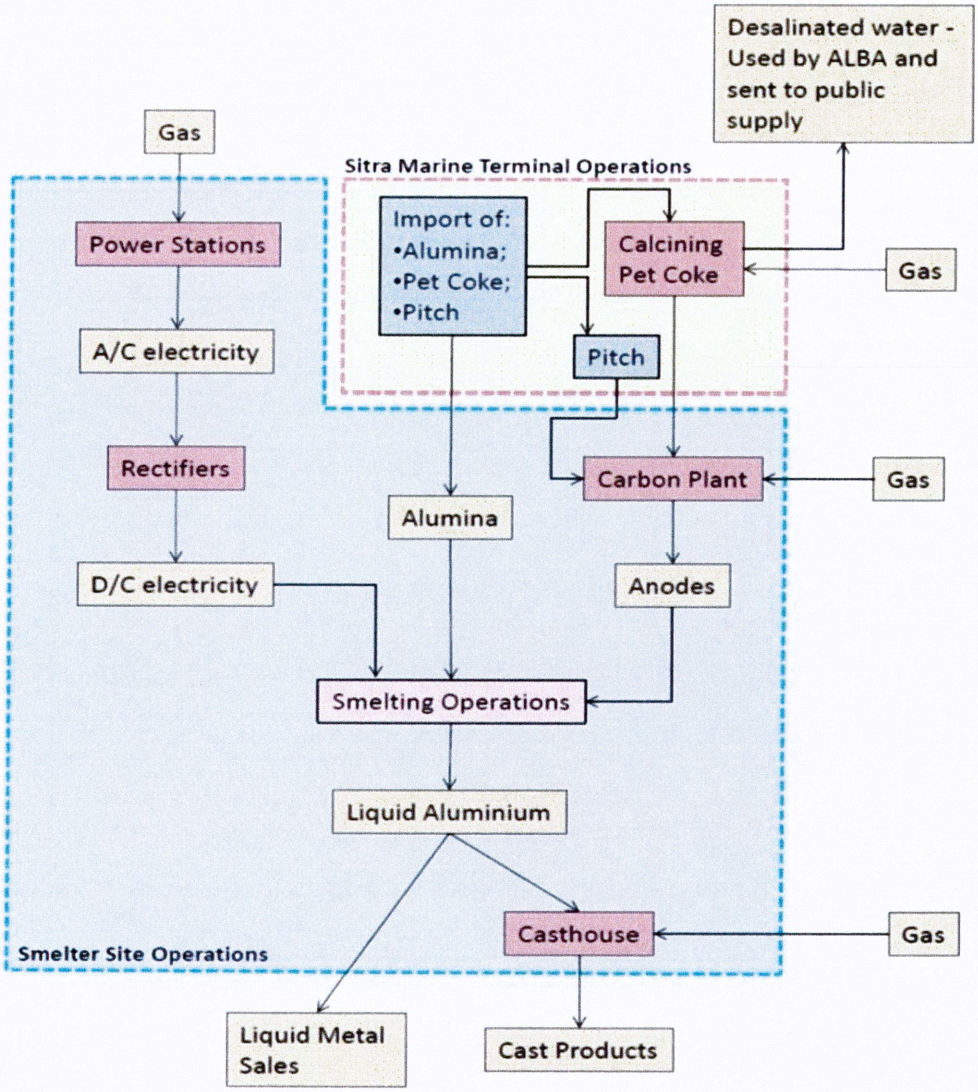


Fig. 4.4: ALBA smelter process (ALBA website)

Marine Terminal and Calciner Plant

The first essential step of ALBA's operation and process starts with receiving the major raw materials at the Marine Terminal, which is located about 10 km from ALBA. The major raw materials are divided into three types include Alumina, Green or unprocessed Petroleum Coke (GPC), and Coal Tar Pitch

(CTP). The company deals with worldwide suppliers to its major source materials, including China, Kuwait, Argentina, and Australia.

ALBA is considered one of the two smelters in the world that dedicated a calciner plant. This plant helps ALBA to eliminate the needs for the Calcined Petroleum Coke (CPC), to be imported from outside. The aim of producing the CPC in-house is to control the quality of the aluminum, since it is one of the main elements used in producing the Carbon Anode.

The calcination process is done through feeding a fired-gas rotary kiln with the GPC. The calcination process temperature is about 1400 °C. The purpose of this process is to get rid of the moisture and improve the density, physical strength, and electrical conductivity of the coke. The steam that is generated from this process with seawater is used to produce desalinated water.

Anode Production

The raw materials are delivered to the production plants of the company by tanker trucks. The Carbon plants are responsible for producing the Carbon Anode blocks, which are made by mixing the CPC with CTP. The Carbon Anode blocks are used to conduct the electricity in the process of electrolysis.

ALBA has four Carbon plants and each plant consists of Paste plant, Kiln plant, and Rodding plant. At the Paste plant, the process starts with crushing and segregating or screening the CPC; in order to be divided into a particular size. Then each size will be measured as per accurate recipe to be preheated before mixing them with the CTP and forming a Green Carbon Anode. The

term 'green' means unbaked anode. The process of baking the Green Carbon Anode is done at Kiln plant, which will be heated to 1185 °C for about 17 days. The aim of this process is to burn the CTP, increase the electrical conductivity, and improve the physical strength of the Carbon Anode. Then, the baked Carbon Anode will be transferred to the last stage of anode production in the Rodding plant. In this plant, the Carbon Anode will be rodded with a conducting rod, to allow the electrical current to pass in the pot room cells. The Carbon Anode needs approximately 28 days to be consumed, and the remains of the Anodes (called Butts) are returned to the Rodding plant again to be recycled.

The Anode production stage is considered as one of the most critical stages in the Aluminum production. It is directly linked with the quality of the aluminum and has an economic impact on the company; due to the price of the CPC and CTP. Therefore, advanced computer technologies are implemented to ensure continuous high quality of Carbon Anodes are supplied to the reduction room. Moreover, they are used to minimize the probability of the defects which have a significant environmental effect; due to the emission of gases during this stage of production.

Reduction Line

ALBA has six reduction lines that are designed to produce a capacity of more than a million ton of molten aluminum per year. ALBA utilizes the electrolysis method in producing the aluminum. This method was discovered independently by two men Mr. Hall in the USA and Mr. Heroult in France in 1886.

The process starts by suspending the Carbon Anode above a steel vessel called a reduction cell where the electrolysis takes place. A part of the Carbon Anode is immersed in the cell to act as a positive electrode (electric current conductor), while the bottom of the cell lining with carbon, which (acting as a negative electrode and it is called cathode), as demonstrated in figure 4.5.

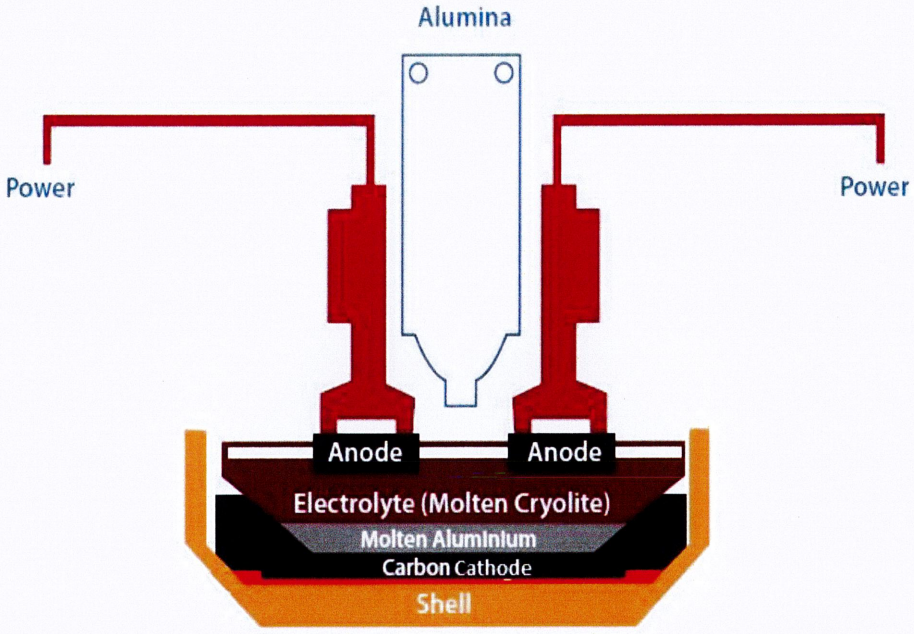


Fig. 4.5: Electrolytic diagram of the reduction cell

Then the alumina is fed into the cells that contain a molten sodium aluminum fluoride (Cryolite) and aluminum fluoride. Alumina is a chemical compound of two molecules, positive ions of aluminum and negative ions of oxygen (Al_2O_3). It is also known as aluminum oxide and it generally looks like a white sugar or powder. The Alumina has to be melted; in order to separate the aluminum ions from the oxygen ions through the electrolysis process .

However, the melting point of the Alumina is very high which is above 1500 °C. Thus, the Alumina crystal is dissolved in the molten Cryolite instead of melting it directly, which requires a vast amount of electricity. The Crylite has a much lower melting point, which reduces the cost that is involved in the aluminum separation process.

A high electric Direct Current (DC) will be applied in each cell and it will be passed from the anode to the cathode electrode, to heat up the cell to a temperature about 960 °C. This moves the positive and negative ions of the alumina in the opposite direction. The oxygen will be raised to the positive carbon anode and form carbon dioxide. While, the pure liquid aluminum will settle at the bottom with the negative carbon cathode. After an interval of time, the pure liquid aluminum will be siphoned or tapped off, using a vacuum crucible. It is a continuous process where the carbon anodes are replaced regularly and alumina is fed into the cells every day; in order to maintain a sufficient alumina in the reduction cell.

The production of 1 kilogram of a pure liquid aluminum requires 1.9 kilograms of alumina, 430 grams of carbon, 19 grams of aluminum fluoride, 50 grams of cryolite, and 14.5 kWh of electricity.

Cast-house

Cast-house is the last stage in the aluminum production process and has a direct contact with the reduction lines. ALBA has four cast-house plants which are responsible to make four different types of the primary products.

The pure liquid aluminum is extracted from the reduction cells and transported to the cast-houses, through Metal Transfer Vehicles (MTV). At the cast-house, the liquid aluminum is transferred to the casting furnaces. In these furnaces the liquid aluminum will be mixed with other metals or alloys, to meet the end-user specifications. These alloys are iron, silicon, titanium, magnesium, and copper.

The liquid aluminum is cast into four primary products includes:

1- Standard or Tee ingots that are used for remelting by industries in their furnaces, to make final products.
2- Rolling Slabs used for finished products, such as packaging products, aviation, and transportation.
3- Extrusion Billets that are used for architectural applications, such as window frames, door frames, and kitchens.
4- Foundry Alloyed Ingots converted into many products, such as pump nozzles, truck tubes, and vehicle wheels.

The company also supplies its product in liquid form to different industries in Bahrain. These industries are located near to the smelter like Midal Cables, Gulf Aluminum Rolling Mill Company (GARMCO), Bahrain Atomisers International (BAI), etc.

Power Plant

The aluminum production process is highly electric power intensive due to the Hall-Heroult electrolytic process. The electricity represents about 30% of the production cost. Therefore, ALBA secured its production through owning five power stations, with a total capacity of 4,041 megawatts (MW).The technology that is used in these stations is combined cycle gas. This technology is very efficient and has less environmental impact, since the generated waste is reused in gas turbines to generate more electricity.

4.7 Carbon Department Structure

Figure 4.6 shows the Carbon Department Structure, where the Instrument section under study is located.

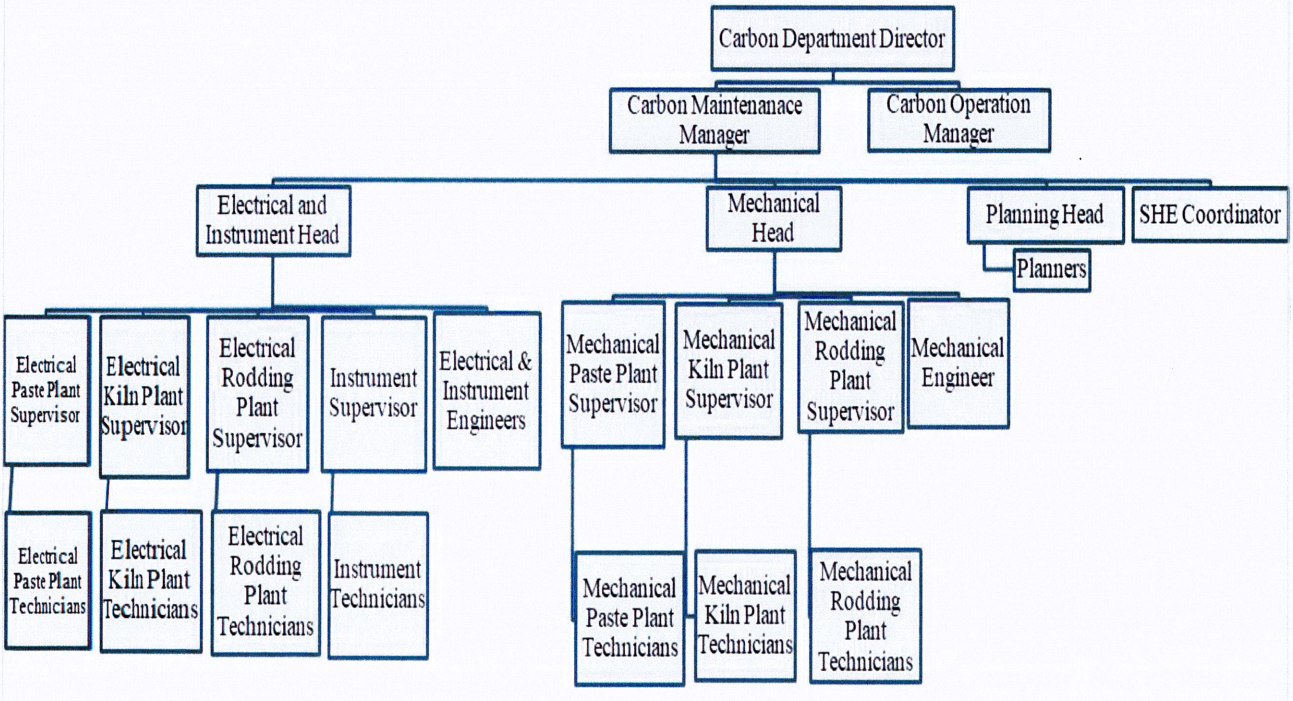


Fig. 4.6: Organizational structure

4.8 Carbon Maintenance Department

The maintenance department is the core and prime mover of the production process. It plays a key role in improving the reliability, and availability of the production equipment and machines. It works day and night to ensure the continuity of high quality anode production with high safety standards at the minimum costs.

There are four carbon plants in ALBA and each plant consists of three main different production plants, such as Paste Plant (PP), Kiln Plant (KP), and Rodding Plant (RP). The equipment and machines are owned by the production department. The maintenance department supports all the plants.

It has three maintenance sections which are Mechanical Maintenance Section (MMS), Electrical Maintenance Section (EMS), and Instrument Maintenance Section. Each plant has separate operation and maintenance crew. However, the IMS, which is also called a plant wide maintenance provider is assigned to do maintenance for all carbon plants. The number of maintenance employees in this department are 250; including 20 supervisors, 5 engineers, and 225 maintenance technicians.

4.9 Instrument Maintenance Section (IMS) of Carbon Department

The Instrument Maintenance Section (IMS) duties are focused on monitoring and maintaining the measurement from the operations using calibrated instruments, such as temperature, level, pressure, vibration, weight, and flow sensors. The main purpose of these sensors is to provide the operation team

the status of the process; in order to be controlled easily. In some systems these instruments are used as a trigger or an input signal for a control system such as Distributed Control System (DCS) or Programmable Control System (PLC). Then, the collected signals (process variables) are compared with the desired values (setpoints), to take an action, such as giving an alarm to indicate the level or temperature is reached, or to open/close an actuator.
The IMS strives to keep the equipment of the plants in the optimum operating conditions, by implementing the latest technologies, such as automation, wireless communication, etc. The IMS task is to ensure that the instruments continuously perform their desired functions and repair the instruments when they fail.

The overall maintenance strategies adopted by the IMS are preventive maintenance and corrective maintenance, with a goal of improving the productivity, reliability, and safety of the production process. Preventive maintenance is a periodic or scheduled maintenance aimed to detect the problems before any serious failure occurs. It includes instrument cleaning, testing, and calibrating. These activities are handled by the IMS crew in the morning shift. It starts with sending the PM sheets by the planning team to the IMS. The flowchart for the Preventive maintenance of the IMS is depicted in figure 4.7(A).

Corrective maintenance is unlike preventive maintenance. The goal of performing the corrective maintenance is to restore a failed instrument to its intended function. It starts with generating a notification by the operation team through the SAP system, to trigger the IMS. The corrective maintenance is handled by IMS shifters, who work in a pattern of 24/7. The shifters are

responsible to solve the problems quickly; in order to reduce the breakdown effect on the production cycle. In case the breakdown requires more time to be solved, the shifters must provide a temporary safe solution and report the day's crew of IMS. The instrument team, who works in days, are required to follow the problem case in order to implement a permanent solution. Figure 4.7(B) describes the workflow of the corrective maintenance.

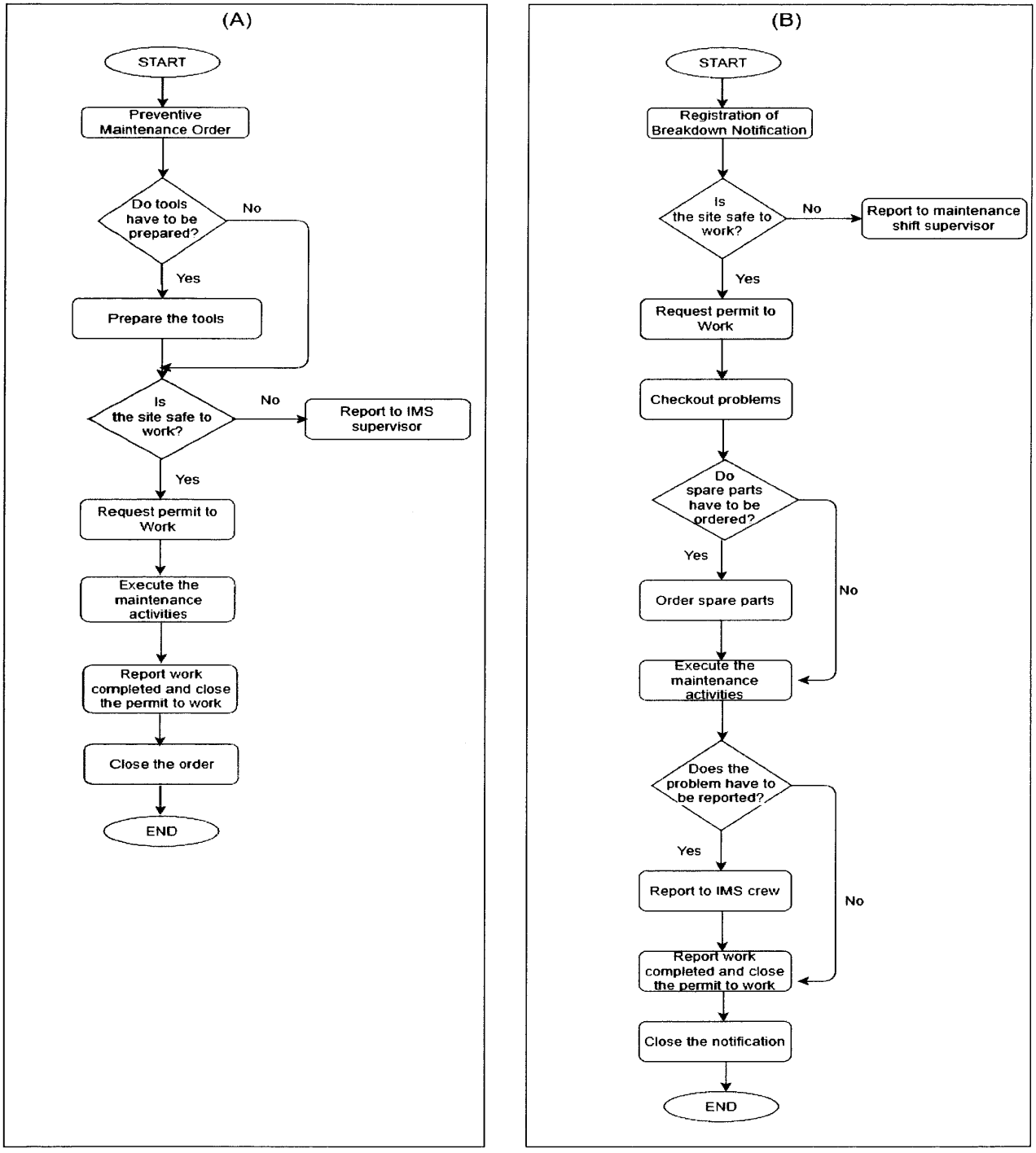


Fig. 4.7(A): Flowchart of Preventive Maintenance,

Fig. 4.8(B): Flowchart of Corrective Maintenance

The IMS data that are recorded in the company system have been reviewed and analyzed. Some of the leading and lagging maintenance indicators have been selected; in order to identify the existing IMS problems and their consequences. This will assist in addressing the gap between the current IMS performance and the required performance. The purpose of identifying the performance gap, is to develop an effective and efficient framework that helps in improving the IMS performance.

The data that have been reviewed is related to the IMS activities for five years starting from 2014 to 2018. The indicators that have been selected are the percentages of proactive, reactive maintenance and modification, or redesign works as leading indicators. While, the lagging indicator used is the number of failures.

Starting with the leading indicators, the world-class maintenance clearly emphasized on the importance of proactive maintenance. It should occupy the highest portion of maintenance activities; in order to reduce the breakdown or reactive maintenance. According to Muchiri (2011), the proactive maintenance of the best word class target is from 75-80% of the total maintenance man-hours. The main objective of proactive maintenance is to identify any abnormal condition or state that may lead to a potential failure and plan for a corrective solution before it occurs. Furthermore, the best world-class maintenance recommended to assign some of the available man-hours to be spent on improvement works, such as modification, redesigning, etc. Muchiri (2011), stated that 5-10% of the total maintenance man-hours should be assigned to improvement work. The aim of the modification work

is to improve the systems by eliminating the causes of the failures and their effects.

Figure 4.9 represents the percentages of different types of maintenance that are carried out by the IMS over the past five years. There is an annual increase in the total man-hours utilized for all activities of maintenance. It also reveals that the proactive maintenance activities are the highest portion amongst other types of maintenance. However, the percentage of reactive maintenance has not decreased as required. It exceeds the recognized limits of the best world class during the last four years. In 2018, the total man-hours of the reactive maintenance have been increased by 180% within the past four years, as shown in part one of Appendix (3). This indicates that the man-hours consumed in the breakdowns and failures have increased by around three times. It signifies the effectiveness of the proactive maintenance, which needs to be evaluated; in order to achieve its key goal. According to the modification work percentage, the IMS allocates some of the available man-hours to improve the systems and operations. However, it is considered insufficient compared with the best world class. Overall, It is evident that when the reactive maintenance man-hours are increased, it affects the man-hours, which are assigned to the other maintenance types, as shown in figure 4.9.

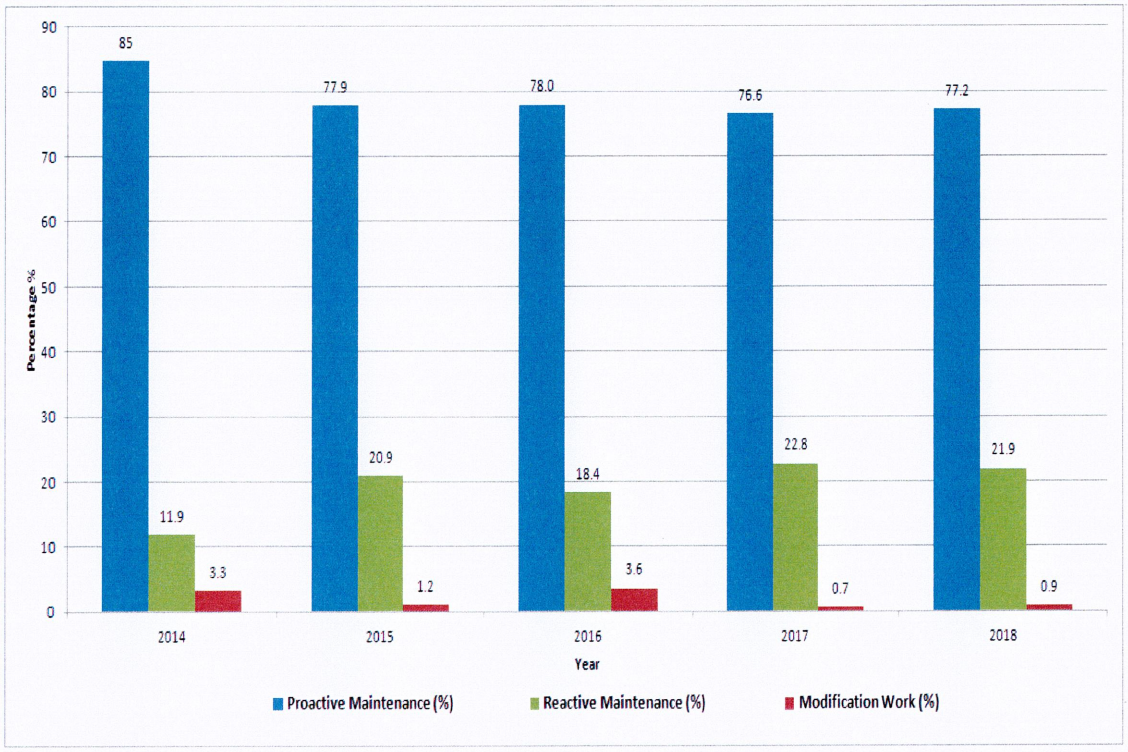


Fig. 4.9: Percentages of maintenance types in IMS

On the other hand, the total number of breakdowns has been used as the lagging indicator; in order to identify and analyze the repetitive failures. The total number of breakdowns is illustrated in figure 4.10. It is clear that the breakdowns pattern of the last three years (2016-2018) of the data collected had dramatically increased. For example, the number of breakdowns in 2016 was 1922 where it jumped to 2936 in 2018, which is an increase by 66%. At the first glance, it is clear that the number of breakdowns in Kiln plant was the highest amongst other plants. The condition of all plants in 2016 was the best, but then the breakdowns increased per year.

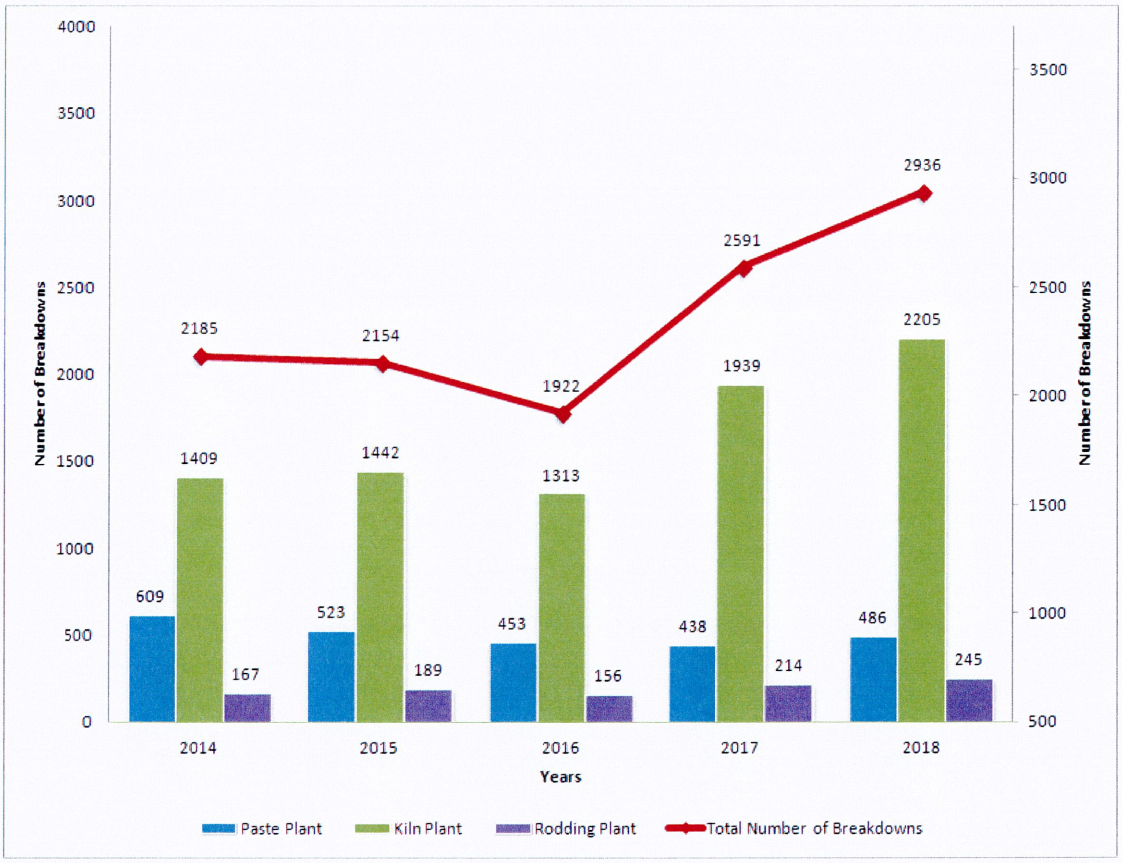


Fig. 4.10: IMS breakdowns from 2014-2018

Since the Kiln plants have the highest number of breakdowns, a deep filtration has been done; in order to find out which breakdowns or failures occur frequently. As a result, the communication failures of the firing system were the most of the repetitive failures with 40% of the total Kiln plant breakdowns and approximately 30% of the total IMS breakdowns. Figure 4.11 below summarizes the communication failures over five years.

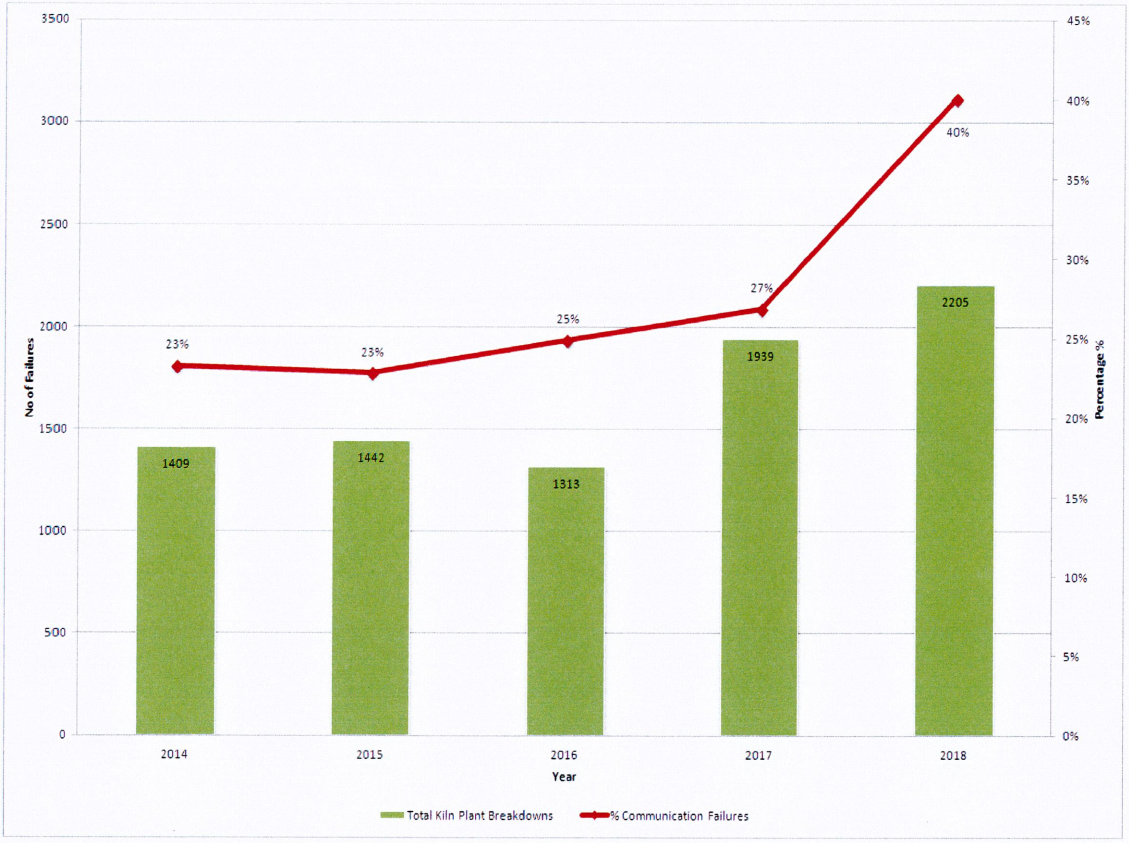


Fig. 4.11: Percentages of the communication failures

This huge number of failures in communication systems, due to a repetitive defect in cables, batteries, cards, and network switches. For instance, in 2018 the communication fails on average twice every day. This problem has a critical effect on the quality of the production system, due to losing the control of the process from the operators. In addition, around two hours of maintenance manpower is allocated for this subject matter. The employee has to work with live and high electric power to solve this issue. The condition of the area is associated with many risks, such as overhead crane movements with suspended load, forklift movement, heat, hot objects, and slippery surfaces.

4.10 Kiln Plant Productions

The carbon anode baking process is considered the most critical and expensive part in the anode manufacturing; due to the fuel consumption and the refractory maintenance cost. The main purposes of the anode baking are to decrease the chemical reaction, by burning the tar coal pitch, increase the conductivity to reduce the power consumption of the electrolytic process, and increase the mechanical strength of the anode. The quality of anode is a key factor that influences the operation costs and the quality of the aluminum.The quality of anode is directly affected by the furnace firing system. Therefore, this system is a critical element, which must be always in its optimum condition to get a better anode quality.

The furnace firing system comprises a set of equipment known as ramps. These equipment are one air blower ramp, one zero point ramp, three gas burner ramps, one measuring ramp, one exhaust ramp, as illustrated in figure 4.12. In each Kiln plant there are more than two firing systems, which vary according to the size of the plants.

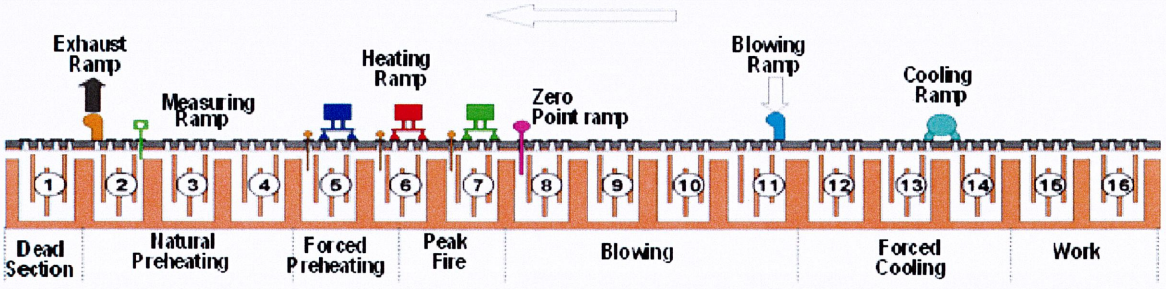


Fig. 4.12: The firing system equipment

All these ramps are integrated to work independently with each other to perform the backing process. Each ramp, is designed to perform specific functions, which are described below:

- Air blower ramp: it is used to supply a sufficient amount of oxygen into the furnace. The amount of the oxygen is regulated by a speed controlled fan according to the pressure measurements of the zero point ramp.

- Zero point ramp: this ramp is used to monitor the pressure of the furnace; in order to keep a zero pressure value behind the last gas burner ramp.

- Gas burner (Heating) ramp: the function of the gas burner ramp is to inject fuel into the furnace; in order to maintain a desired temperature. The temperature sensors are used to monitor the temperature for a purpose of controlling the temperature profile, by regulating the fuel pulsation.

- Measuring ramp: the aim of this ramp is to monitor the pressure and temperature of the furnace, and some anode temperature through different types of instruments, such as pressure and temperature sensors. Then the measured data are transferred to the Exhaust ramp through an industrial Ethernet network, to perform the control action using motorized control dampers.

- Exhaust ramp: Exhaust ramp is used for collecting and controlling the waste gases from the furnace. It also links the furnace with the main gas duct that is used to transfer the waste gases to the Fume Treatment Plant (FTP); in order to be converted to harmless gases.

- Cooling ramp: this function ramp is used to cool the baked anodes by supplying a sufficient air inside the anode pit.

All the anode baking furnace operations are monitored and controlled by the operators from a central control room through a PC software called ProBake. The general task of the ProBake in the automatic mode is to perform all supervision, visualization, and control the baking process, while the Programmable Logic Controllers (PLCs) of the ramps act as a data acquisition and system actuator. The ProBake system is communicating with the ramps via an industrial network, which it allows the authorized operators to send the target parameters to the ramps.

The quality of anode baking is determined by the temperature over time curve or temperature profile. Therefore, the communication must be healthy all time in order to link the ProBake system with the PLCs of the ramp to achieve the optimum quality of baking. Otherwise, any failure in the communication between the ramps and the ProBake system will affect the temperature profile, which will be directly reflected in the anode quality.

Finally, it is clear that the carbon department plays an important role in the process of the aluminum production. The maintenance activities of the carbon department must be managed effectively; in order to achieve the targets of the

company. The impact of an effective maintenance management will directly improve the plant production capacity, production costs, and safety, health, and environment issues.

The IMS current performance has been analyzed; in order to identify the existing issues with the help of some leading and lagging indicators. The indicators that have been selected are the percentages of proactive, reactive maintenance and modification, or redesign works as leading indicators. While, the lagging indicator used is the number of failures. The results revealed that the reactive maintenance portion is increasing, leading the other maintenance types to be missed. Based on the records that are shown in figure 4.10 & 4.11, the most breakdown item occurred is communication failures which need to be actively traced in order to minimize the effect of the unplanned activities. Most of the companies seek to achieve world class by eliminating or reducing the reactive maintenance portion (fire-fighting), and maximizing the proactive maintenance activities, such as preventive and predictive maintenance. Without an effective and efficient maintenance management framework, the world class will not be achieved. Therefore, this research will evaluate the present maintenance practices of IMS, to identify the reasons that caused an increase in the reactive maintenance portions. In addition, the key factors that influence the performance of IMS will be identified; in order to establish a solid framework, which will assist the department to achieve their objectives.

Chapter Five

Data Analysis and Discussion

5.1 Introduction

5.2 Questionnaires and Interviews administration

5.3 Preliminary Information

5.4 Questionnaire Results

5.5 Interview Results

5.6 Discussion

5.7 Conceptual Framework

5.8 Conceptual Framework Validation

5.1 Introduction

The aim of this chapter is to analyze and discuss the data, which has been collected by means of interview and questionnaire. The interview targeted to collect data from the management levels and it is represented as descriptive data, where the questionnaire survey was designed to receive data from non-management levels and use statistics as a data representation.

5.2 Questionnaire and Interview Administration

The data of this part has been obtained from two different levels of staff to have a solid picture about the current practices from all aspects of maintenance. The first level are those who are implementing the maintenance tasks, which are the non-management staff. While, the other source of data is from the maintenance management level who are managing the day-to-day maintenance activities, planning the maintenance activities, and reviewing the equipment performance.

The maintenance issues that potentially affect the maintenance performance, which are covered in the previous studies have been identified and reviewed; in order to formulate the questionnaire surveys and the interview questions.

- **Questionnaire Surveys**

The total number of questions was filtered to 38 questions; divided into two groups. The first group of questions was designed to have a knowledge about the maintenance personnel responsibilities and how they react with the maintenance request like breakdowns. It also focused on understanding the failures of the firing system and their main causes. While, the second group

of questions was related to the factors that affect the IMS performance. The questionnaire was a combination between open-ended and closed-ended questions. It was targeted to all IMS non-management employees, which are 25 in number. However, the received data were only 20 respondents. This represents a response rate of 80%.

The response rate was hardly obtained due to the Covid-19 epidemic. This rate was achieved through constant phone calls and text messages as gentle reminders to fill the electronic form. The electronic form was issued in order to minimize the direct contact with respondents.

- **Interview Questions**

A semi-structured interviews were used to collect the required information from the management level. The interviews were conducted with the following: Head of maintenance, Head of planning, and supervisor of maintenance. The average time spent in each interview was one hour. The interviewees were selected according to their positions which represent the management level feedback of the IMS and managing day to day maintnenace activities. The purpose of the interviews was to get in depth information and knowledge about the present state of the maintenance practices from the management perspective. The interview questions have been prepared by the researcher and they were focused on three main parts: maintenance planning, maintenance performance measurement, and maintenance management, as it is shown in Appendix (2). The data of the first two main parts were collected from the head of planning, whereas the data of the third part were collected from the supervisor and the head of maintenance.

All interviews started with general questions to have preliminary information about the interviewees such as the age, years of experience, highest qualification they have, and their opinion about the operational performance of the carbon department.

- **Interview and Questionnaire Survey Validation**

The researcher met the maintenance manager and two technical experts in order to discuss the interview and questionnaire surveys. The purpose of this meeting was to evaluate the interview and survey questions to ensure that the questions effectively capture the research problem. The feedback of this meeting helped positively in reconstructing the questions. It also helped in eliminating the inapplicable ideas, irrelevant questions and common errors in the questions in order to enhance the reliability of the collected data.

The pilot study was conducted before collecting the research data in order to ensure the reliability, comprehension and accuracy of the interview and survey questions. It aims to enhance the validity of the questionnaires by giving the chance to revise again the constructed questions. The first three responses were used as a pilot study.

- **Reliability Test**

The reliability test has been conducted to ensure the quality of the collected questionnaire surveys. Cronbach's alpha was performed to measure the consistency of the questionnaire. The values of Cronbah's alpha are normally between 0 and 1. The higher values of alpha reflect higher internal consistency of the constructed questionnaire. Devellis (1991) stated that, the Cronbach's alpha must not be less that 0.6 in order to accept the collected data. The

Cronbach's alpha of the research questionnaires calculated and summarized in Table 5.1.

Table (5.1): Cronbach's Alpha Analysis

No.	Item	No of Statements	Cronbach's Alpha
1	IMS present practices	19	0.828
2	IMS challenges	11	0.859

Table 5.1 shows that the Cronbch's alpha values of the IMS present practices and IMS challenges are greater than 0.8. Therefore, this is an indication that the collected study data through the adopted scales were reliable and the questionnaire surveys were valid and reliable.

5.3 Preliminary Information

The goal of this section is to briefly describe the participants' feedback on this research, who had been interviewed and completed the questionnaire. Table 5.2 summarized the participants' profile with respect to the following variables: participants' age, years of experience, qualification, and position. In addition, Table 5.2 presents the participants' opinion on the overall performance of the Carbon department.

Table (5.2): The Participant Profile

Participant Details	Categories	Frequency	Percentage
Age	From 20 - 30 years	2	9%
	From 31 – 40 years	7	30%

	From 41 – 50 years Above 50 years	8 6	35% 26%
Years of experience	1- 3 years 4-10 years 10-15 years Above 15 years	2 4 1 16	9% 17% 4% 70%
Qualification	Diploma Bachelors Master	12 10 1	52% 44% 4%
Position	Technician Senior Technician Maintenance Supervisor Head of Planning Head of Maintenance	16 4 1 1 1	70% 17% 4% 4% 4%
Participant Opinion			
Operational Performance of Carbon Department	Very good Good Average Poor Very poor	0 6 13 4 0	0% 26% 57% 17% 0%

Age: Figure 5.1, indicates that most of the participants are from 41 to 50 years, which represent 35% of the sample, whereas the lowest percentage of the participants' age is between 20 to 30 years old representing 9% of the samples. It also shows that 30% of the sample are from 31 to 40 years old,

while 26% of the sample represents the participants who are above 50 years old.

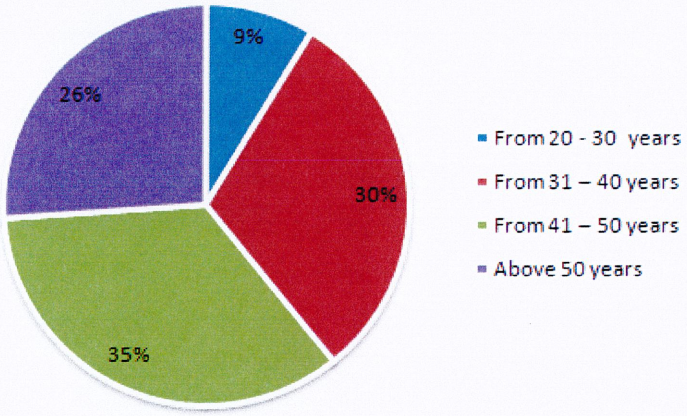


Fig. 5.1: Participants' Age

Years of Experience: Figure 5.2, indicates that the highest percentage of participants having above 15 years of experience, which represent 70% of the sample. The second highest percentage is 17% of the participants who have 4 to 10 years of experience. It also indicates that 9% of the sample have 1 to 3 years of experience, while the lowest percentage is 4%, which represents the sample who have 10 to 15 years of experience.

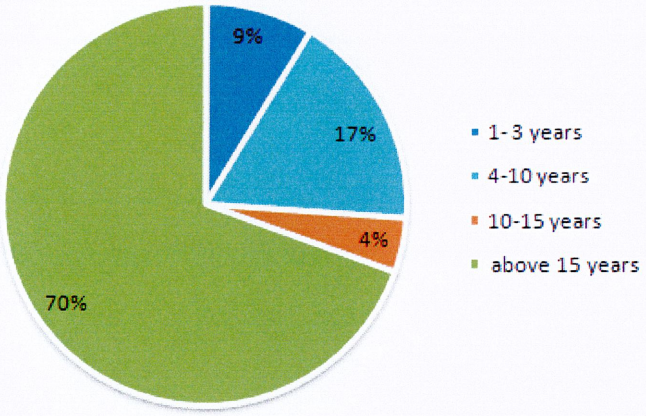


Fig. 5.2: Participants' Experiences

Qualification: Figure 5.3, indicates that the majority of the participants are "Diploma" holders, with 52% of the sample, since most of the participants are technicians. Whereas, 44% of the sample are " Bachelor" holders, and 4% of the participants are representing the "Master" holders.

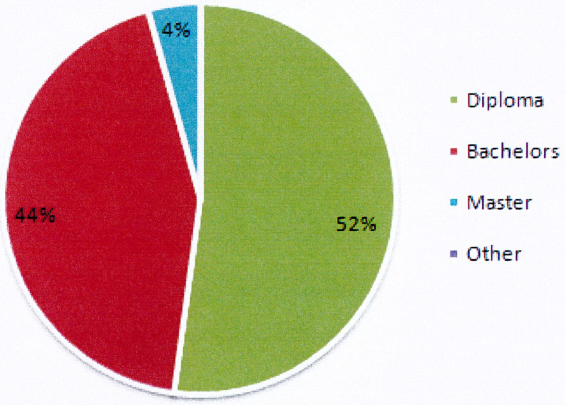


Fig. 5.3: Participants' qualification

Position: Figure 5.4, indicates that the position distribution the majority of the participants are technicians and senior technicians, 70% and 18% respectively. Also, 12% of the participants are from management, which include the head of planning, head maintenance, and the supervisor of maintenance.

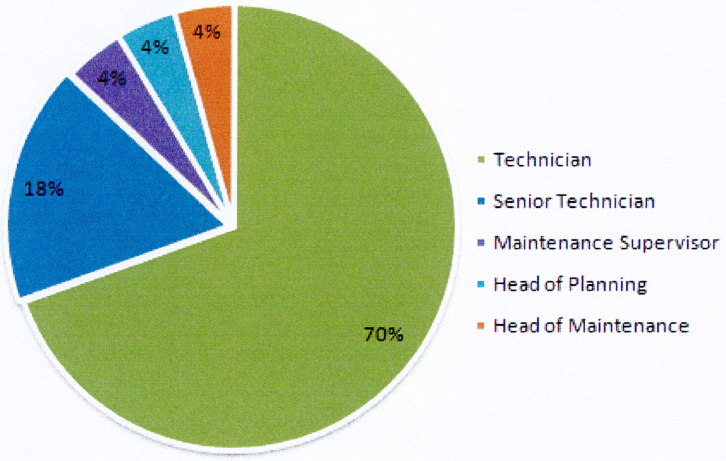


Fig. 5.4: Participants' position

Carbon Operational Performance: Figure 5.5, indicates that the majority of the participants agreed that the current operational performance of the carbon department is considered to be average.

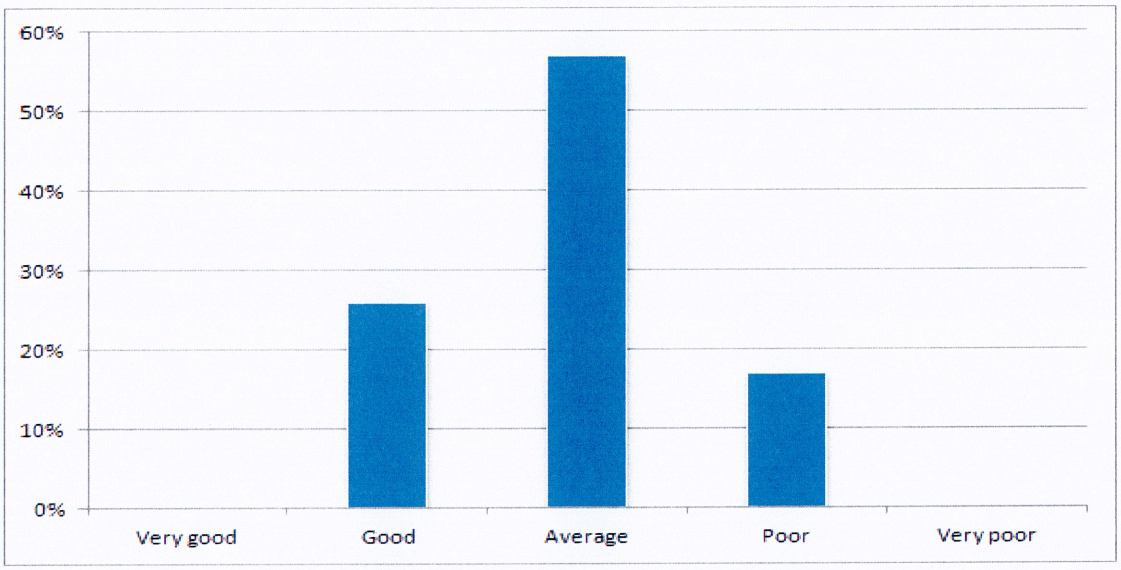


Fig. 5.5: Carbon operational performance

5.4 Questionnaire Results

It is important to know the existing practices or how things are performed; in order to figure out the gap between the present environment and the desired state. This can be done by comparing the current state of others who are performing very well. For the research case, it is an essential step to identify the present practices of IMS, so that it can be compared with the best practices, which are covered in the literature. The key role of this step is to know how the existing practices affect the IMS performance, so that an efficient framework can be formulated.

The non-management staff were asked about their opinions on the present maintenance practices of the IMS. In addition, they were asked about the nature of the failures of the firing system and the major causes of the repetitive failures. The questionnaire was mixed in nature between open-ended and closed-ended; in order to get the advantage of both.

- **Present Maintenance Practices**

The first question in this part was to identify the present maintenance practices, by using nineteen statements. Each of these statements has five likert scale, ranging from (always) practiced or implemented to (never) exists. Table 5.3 illustrates the summary of the results.

Table (5.3): Present Maintenance Practices

No.	Practice	Always %	Most times %	Sometimes %	Rarely %	Never %	Highest Percentage of Practice
1	Main causes of repetitive failure are known	10	35	50	5	0	50
2	Breakdowns occur daily	85	10	5	0	0	85
3	Immediate action is taken on sudden breakdowns (unplanned breakdowns)	25	45	30	0	0	45
4	Planned maintenance activities affected when breakdowns occur	25	50	25	0	0	50
5	Failures recognized before it occurs	5	5	35	50	5	50
6	Receiving support from the supervisors when performing the maintenance activities	55	15	25	5	0	55
7	Proper tools used to perform the maintenance activities	55	10	15	10	10	55
8	Tools kept in the proper place	60	25	5	10	0	60

9	Availability of spare parts when needed	10	25	55	5	5	55
10	Spare parts stored in the proper location	50	30	15	5	0	50
11	Inventory managed and controlled efficiently in the warehouse	10	55	30	5	0	55
12	Commitment with safety procedures	80	20	0	0	0	80
13	Keeping records for any projects, modification or redesigning work.	20	40	30	10	0	40
14	Involving in operational projects, equipment modifications, and process changes.	10	5	35	45	5	45
15	Receiving adequate training in the production process and operation.	10	20	20	45	5	45
16	Receiving adequate training on the latest technologies to improve the maintenance activities.	5	30	5	5	55	55
17	Receiving training in methods, techniques and applications to assist in the failure analysis.	5	25	40	15	15	40
18	Safety of manpower and environment issues are controlled.	50	35	5	10	0	50
19	Sufficient resources allocated for planned maintenance activities.	15	45	35	5	0	45

The results reveal that 85% of the participants agreed that the breakdowns occur daily and the main causes of the failures are sometimes known as confirmed by 50% of the participants. About 45% of the participants said that an immediate action is taken on sudden breakdowns most times. Whereas, 50% of the participants agreed that the planned maintenance activities affected when breakdowns occur the most times, and 50% of the participants agreed that the failures rarely recognized before they occur. The statement of "Receiving support from the supervisors when performing the maintenance activities" was confirmed by 55% of the participants as always there. With regards to the tools, 55% of the participants said that they always use proper tools to perform the maintenance activities and 60% of the employees agreed that tools always kept in the proper place. On the other hand, 55% of the participants agreed that the spare parts are sometimes available when needed.Once the spare parts are available, they are always stored and kept in the proper location as confirmed by 50% of the participants. Whereas, 55% of the participants believed that most of the time the inventory was managed and controlled efficiently in the warehouse. Regarding the commitment to safety, the majority was always committed with safety procedures which was confirmed by 80% of the participants. While, 50% of the participants agreed that the safety of manpower and environment issues are always controlled. About 45% of the participants said that they are rarely involved in operational projects, equipment modifications, and process changes, and 40% of the participants agreed that they are keeping records of any project, modification or redesigning work most of the time. In relation to the training, 55% of the participants believed that they never received adequate training on the latest technologies to improve the maintenance activities. While 40% of the participants agreed that they sometimes received training in methods,

techniques and applications to assist them in the failure analysis, and 45% of the participants said that they rarely received adequate training in the production process and operation. About 45% of the participants agreed that there are sufficient resources allocated for planned maintenance activities at most times.

- **Maintenance Procedures**

The second question was to determine whether the maintenance procedures in place are adequate or not. Figure 5.6, shows that 55% of the participants agreed that the maintenance procedures in place are adequate, while 45% said the existing maintenance procedures are inadequate.

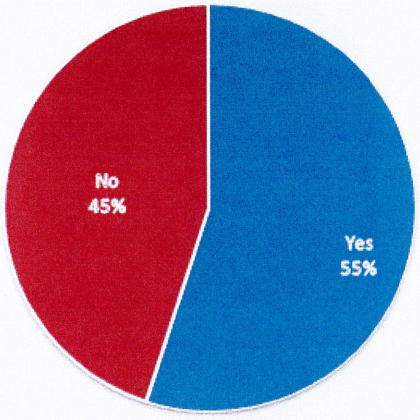


Fig. 5.6: Adequate maintenance procedures

- **Training Schedule Plan**

With regard to the training schedule plan, 60% of the participants answered there is no clear training schedule plan for the maintenance team. Whereas, 40% of the participants agreed that there is a clear training schedule, as shown in figure 5.7.

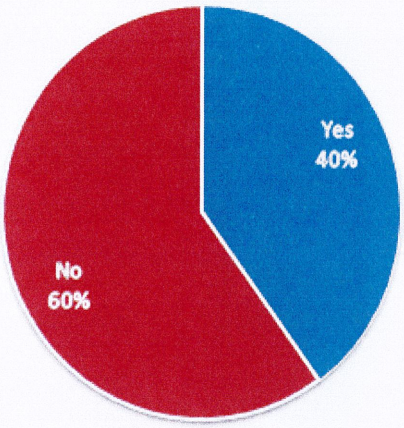


Fig. 5.7: Training schedule plan

- **KPIs Sharing**

In relation to the Key Performance Indicators (KPIs) analytic, about 70% of the participants said that the KPIs are not shared with them. The rest of the participants agreed that the KPIs are shared with them as shown in figure 5.8.

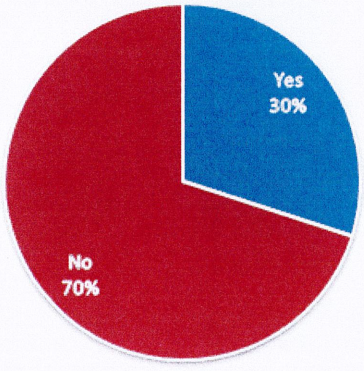


Fig. 5.8: KPIs sharing

- **Maintenance Practices Implemented**

100% of the participants agreed that there are different maintenance practices implemented in the IMS. These practices are breakdown maintenance, corrective maintenance, and preventive maintenance. Moreover, few of the participants answered that the predictive maintenance is implemented to predict the failures using their experience only such as vibration, heat, abnormal sound etc.

- **Firing System**

Regarding the firing system, the participants were asked to list the nature of failures they faced in checkbox question type. The participants had an extra option to add any failure that is not mentioned within the given options. Figure 5.9, below represents the nature of the failures of the firing systems and their percentage of occurrence according to the participants' experience.

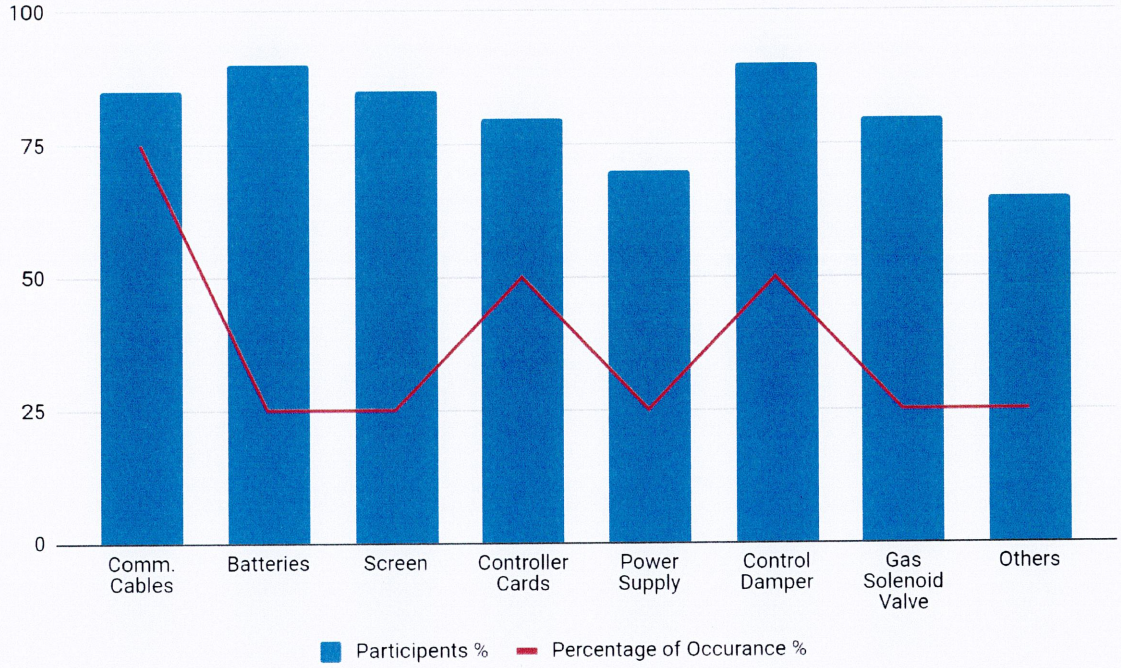


Fig. 5.9: Failure types in the firing system

85% of the participants have experienced issues in the communication cables and it represented 75% occurrence rate. 90% of the participants have experienced issues in the control dampers and it represented 50% occurrence rate. The failures of the control cards had the same percentage of occurrence of the ramp control damper according to 80% of the participants who faced this issue. The breakdowns that related to batteries, power supplies, panel views, and gas solenoid had the lowest percentage of occurrences which is 25% according to more than 65% of the participants. Moreover, about 65% of the participants had other breakdowns, such as network switches and sensor failures. However, the percentage of the occurrence of these types of breakdowns is low which does not exceed 25% of the total breakdowns they faced.

- **Repetitive Failure Causes**

The participants were asked about their opinions on the causes of the repetitive failures; in order to have more information and knowledge of the major causes. The participants have been given a list of possible causes to select from and to write the occurrence percentage according to their experience. The participants had an extra option to any causes that they feel it is related to these failures. Table 5.4 illustrates the summary of the results.

Table (5.4): Repetitive Failure Causes

No	Main Causes	Percentage of Occurrences				
		0%	25%	50%	75%	100%
1	Vibration	20	45	25	10	-
2	Heat	-	20	10	25	45
3	Insufficient preventive maintenance	40	15	40	25	-
4	Improper equipment handling	-	15	20	30	35
5	Minor faults ignorance	50	40	20	10	35

Table 5.4 shows that about 70% of the participants agreed that the main cause of the repetitive breakdowns was the heat or the high temperature of the environment and it represented 75% to 100% occurrence rate. 65% of the participants agreed that the second highest reason of the repetitive breakdowns was related to the user which is the improper equipment handling. Insufficient

preventive maintenance was the third main cause that was confirmed by 65% of the participants as a reason for 50% to 75% of the repetitive breakdowns. Furthermore, vibration and minor fault ignorance were the lowest percentage as causes of the repetitive breakdowns according to the majority of the participants.

- **Factors Affecting Maintenance Performance**

The participants were requested to indicate the challenges or barriers that influence the IMS performance when implementing the maintenance activities, by using eleven statements as shown in part three of Appendix (3). Each of these statements has five Likert Scale, ranging from 1 (Strongly Disagree, SD) to 5 (Strongly Agree, SA).

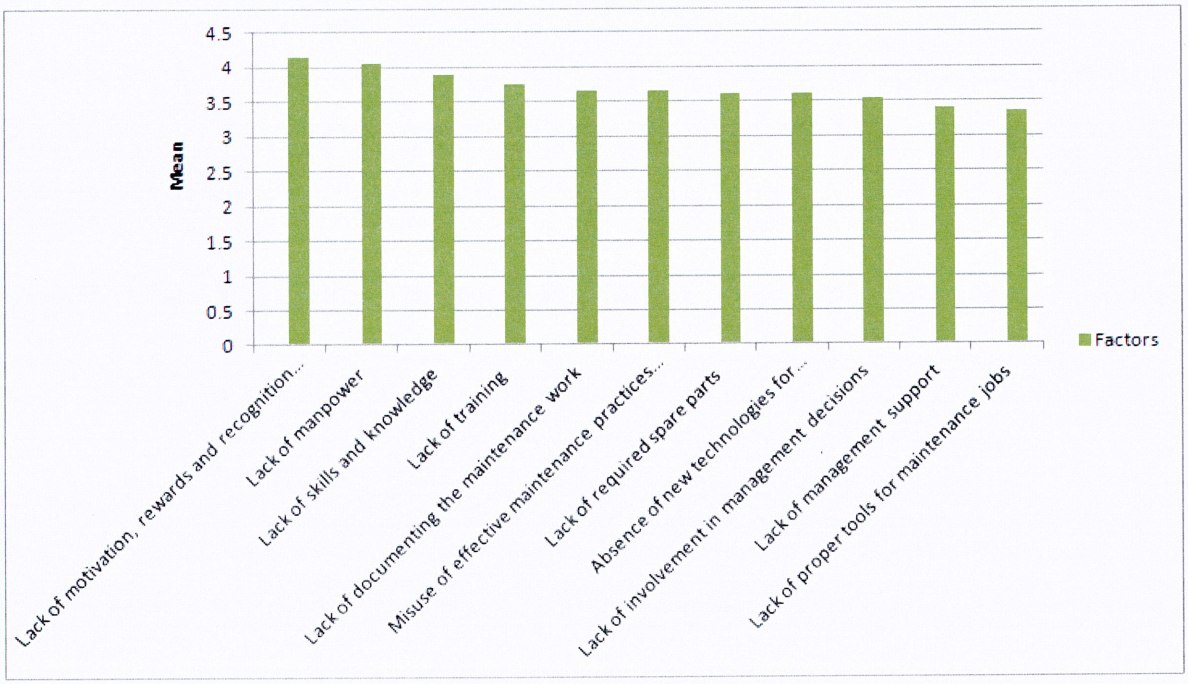


Fig. 5.10: Ranking of factors affecting IMS performance

Figure 5.10 illustrates the ranking of the factors that influence the IMS performance from the highest to lowest factors.The results revealed that the mean scores of the 11 factors varied from 3.35 (the lowest) to 4.15 (the highest) out of a possible range of 1.0 to 5.0, where 1.0 means strongly disagree and 5.0 indicating strongly agree that the factor has a high impact on the IMS performance. From the results, it can be noticed that each factor plays an important role in the IMS maintenance performance. As perceived by the participants, the highest factor that influences the IMS performance was the lack of motivation, rewards and recognition systems. The second highest factor was the lack of manpower. This was followed by the lack of skills and knowledge and lack of training. The least factors were lack of proper tools for maintenance jobs, lack of management support, and lack of involvement in management decisions.

5.5 Interview Results

Part (A): Maintenance Planning

1- Is there a planning system for your maintenance activities? If Yes, how frequently is it?

The interviewee mentioned that there are two types of schedules. The weekly schedules or weekly planning activities that include daily running checklists and PM checklists for the shutdown plants. The other one is the yearly schedules, also called yearly planning activities, which should be prepared at the end of the year for the year after. The yearly schedules are designed mainly for the major shutdowns or major projects.

2- How is the maintenance plan selected?

The maintenance plan is selected according to manufacturer recommendation. For each equipment installed, there will be a document called, Original Equipment Manufacturer (OEM). This document will give the user a full picture about the operational sides for the equipment, the spare part details and what are the recommended procedures to be followed for the maintenance. For example, It will tell the user where to check and frequency of the lubrication if required and its type, etc. The maintenance plan will be updated periodically according to the operational performance of the equipment and the supervisors' recommendations.

3- Are the maintenance activities recorded after execution of the maintenance tasks?

All interviewees noted that, for the corrective maintenance activities, the operation team must open a breakdown notification in the Enterprise Resource Planning (ERP) software, stating the main problems. Then, the notification will be filled by the maintenance crew, who attained the breakdowns and execute the maintenance work to mention the full details about the problems and how it gets solved. The maintenance supervisor's responsibility is to check and close all the breakdowns notifications that are filled by his team.

With regards to the preventive maintenance (PM) activities, the interviewee mentioned that the maintenance task that is accomplished will be recorded on the PM sheet, then signed by the person who completed the task and the maintenance supervisor. The PM sheets are then collected by the planning section in order to be recorded in the ERP system.

4- Are maintenance tasks evaluated after recording them? Why?

For the PM orders, all PM sheets will be checked after receiving them from the maintenance supervisor; in order to know whether the activities are done or cancelled. If cancelled, the reason must be stated clearly so that the planning team will reschedule the activities. The main reasons for the evaluation are as follow:

- To analyze the collected data; in order to identify the problems, the possible causes, and then plan for effective corrective actions.

- To determine the maintenance cost spent on the equipment and calculate the depreciation expense; in order to match the total expenses with the total revenues that were received for the equipment. This helps in making a decision like keeping or replacing the equipment.

- To Measure the effectiveness of the maintenance activities to be compared with maintenance KPIs. Hence, determine whether the maintenance objectives, and goals of the company achieved or not.

In addition, it was stated by the head of planning section that there is an essential need to enhance the quality of maintenance records because it highly affects the KPIs evaluation. For example, some closed notifications are written without providing enough details about the maintenance activities implemented or unclear language. Therefore, they require more training on how to write the reports, since it directly affects the reliability of the data, which affects the results of the evaluation.

5- What current workflow system does IMS follow?

The preventive maintenance activities are scheduled automatically through the ERP system according to the maintenance frequency. With regards to the corrective maintenance, the IMS crew will respond to the breakdowns that are received through the ERP notifications. However, it was pointed out by the head of maintenance that currently there is a need to standardize the workflow to be explicit for all departments. For example, in case there is an issue with the quality of the production, the process team will ask the maintenance crew to make a solution without notifying the planning team. Or, the operation team will communicate with the engineering department to implement new projects without a direct involvement of IMS team.

Part (B): Maintenance Performance Measurement

a. What type of key maintenance performance indicators do you use?

KPIs are shown in Table 5.5 below.

Table (5.5): Current IMS Maintenance KPIs

No.	Maintenance KPI	Target/ Baseline
1	Titan project (YTD)	M$
2	Schedule Attainment	> 95 %
3	Manpower Utilization	> 95 %
4	PM Compliances	> 95%

5	Breakdown Notification Outstanding	< 5 %
6	Maintenance Cost per MT	14.582 BD/MT

2- How KPIs are selected and how frequently reviewed?

The KPIs are selected according to the maintenance objectives. Where these objectives are derived from the company goals. The KPIs list will be effective when they are evaluated accurately and periodically, since the data represent the performance or how far are you from the desired outcomes. The KPIs are reviewed on a weekly basis by the planning team and a monthly basis by the top management, so that corrective actions will be performed as needed to achieve the objectives. In addition, to ensure that the maintenance performance is always in the circle of the continuous improvements.

3- Are the KPIs' reviews shared with all IMS crew?

The planning team is responsible to share the KPIs reviews to the maintenance head. Then, the maintenance head is responsible to communicate the KPIs reviews to the maintenance sections' supervisors in order to ask their team to implement the required activities to achieve the target of the assigned KPI.

4- Are Overall Equipment Effectiveness (OEE) determined for the Carbon Department, and how are they calculated?

It is not currently used, however, there is a plan to be used soon.

5- How do you review the maintenance objective to be appropriate with key performance indicators?

Selecting the maintenance objectives must be aligned with the company policies and goals. The top management represents the statements of what must be followed and achieved, in terms of the safety and department goals.

Part (C): Maintenance Management

1- Are Maintenance activities considered as a strategic factor in developing the department?

The interviewees said that, It must be given enough consideration; in order to get the Return of Interest (ROI) through process improvement which can be directly reflected on the quantity and quality of the produced anodes. However, in few cases the maintenance activities that required a lot of resources will be on hold. This is due to the limitation on budget that is allocated for each section or due to minimizing the resources given to the maintenance or operation sections to achieve an assigned target as a cost saving. Moreover, the maintenance activities such as preventive maintenance, must be studied before deciding to cancel or to keep on hold, because it may affect the entire production process in future. This will identify how well the management aware of the benefit of the maintenance activities. The maintenance activities should be considered as a profit center even when the results will be achieved after a certain time.

2- Does top management support you?

The interviewees indicated that most of the time support is given. This is due to the business strategies, which must act as the main link between the departments and sub departments of the company. For example, the titan project, which is considered as a strategic financial goal to reduce the operational costs, since the competitiveness between smelters over the world is increasing. Where each and every smelter was looking to reduce that production cost. As a result, it will reduce the resources required by the maintenance to the lowest acceptable limits as a cost saving plan. Or minimizing the overtimes by offering extra hours with off days to be aligned with the vision and mission of the company.

3- Is there good communication between the maintenance and production department?

The interviewees stated that there is good communication, but not solid as required. The point of view of the interviewees is that it needs a procedure that gives the maintenance team a right to be involved before making a decision in doing major changes in the operational processes. Because this may have a direct effect on the equipment and machines that are maintained by the IMS crew. In addition, the operation team has to be committed more with the PM schedules, where in some cases the equipment or machine will not be given to be maintained, by the maintenance crew; in order to achieve the production targets.

4- Are employees involved in management decisions?

The emplyees from non-management level are not always involved in the decision cycle, which depends on the criticality of the situation. In some situations, even the management level will not be involved, only top management are involved. However, there is a noticeable improvement compared with the previous years.

5- Is the operation team involved in the basic maintenance work?

Some of the employees in the operation team have a long experience in the plants. However, these employees are few and they are almost at the retirement age. Therefore, the operation management must train their employees to have enough skills and knowledge; in order to help the maintenance team in doing basic maintenance works.

6- Does management support continuous improvement in maintenance practices?

The management supports continuous improvement in maintenance practices through the following points:

- Reviewing the department and business objectives; in order to identify any changes and accordingly do the required changes to ensure that the maintenance objectives are always aligned with them.

- Continuously reviewing the measured performance, to evaluate the current state of the maintenance practices.

- Assessing the equipment that have the largest impact on the operations and identifying the critical systems and components; in order to set the objectives.

- Short meetings on a periodic basis with the non - management team, who is performing the maintenance activities to study the repetitive breakdowns and provide permanent solutions.

7- Is there a particular method or tool conducted to find the root causes of the repetitive failures?

Currently, there is no such formal or periodic method used in place. However, a group meeting is conducted when there are repetitive breakdowns, to share the individual experience between the team; in order to analyze the main causes and solve them.

8- How do you review the maintenance strategy alignment with the maintenance objective?

By continually reviewing the department and business objectives in order to make the required changes accordingly and ensure that the maintenance objectives are always aligned with them. For example, the company has set a financial objective to reduce the controllable costs; in order to achieve the production target with the minimum cost to stay competitive in the worldwide market. To achieve this, in 2014 the company has launched a project called 'Titan' with an aim to reduce the cost by $100 million by the end of 2020. Therefore, to achieve this business objective, each department has been responsible to set strategies for cost-improvement in PM materials, maintenance overtime expenses, etc.

Furthermore, focusing on the customer priorities (operation team) and reviewing the maintenance strategies, such as reducing the number of breakdowns of the critical equipment by improving the preventive maintenance practices. And analyse the impact of the non-critical equipment to be assigned to corrective or run to fail maintenance in order not to disturb the production cycle for unnecessary scheduled maintenance.

5.6 Discussion

This part presents the case study data collected, questionnaires, and interivews data analysis

Breakdown Analysis using Pareto Chart

The conclusive analysis has been found that the reactive maintenance man-hours and the number of breakdowns were dramatically increased over time.. According to the analysis shown in figure 4.9, the Kiln plants had the highest number of breakdowns compared with the other plants and the total number of breakdowns increased over the last four years. Hence, the aim of this part was to reduce the number of breakdowns in the Kiln plant to reduce the reactive maintenance man-hours.

The analysis of this part starts with the existing data and it has been focused on the year that had the highest breakdowns which was (2018), as shown in Table 4.3. The list of breakdowns and the number of occurrences is shown in Table 5.6, whereas, Figure 5.11 presents the most frequent occurrence, based on the Pareto analysis.

Table (5.6): Breakdown elements of Kiln Plants including frequency and percentage for year 2018

No.	Breakdowns	Frequency	Frequency %
1	Communication Failures	883	40%
2	Ramp Control Dampers	523	24%
3	Panel views	386	18%
4	Sensor Failures	175	8%
5	Gas Solenoid Valves	80	4%
6	FTA Compressor	68	3%
7	Anode Slot Cutting Machine	34	1%
8	Other	56	2%
	Total:	2205	100%

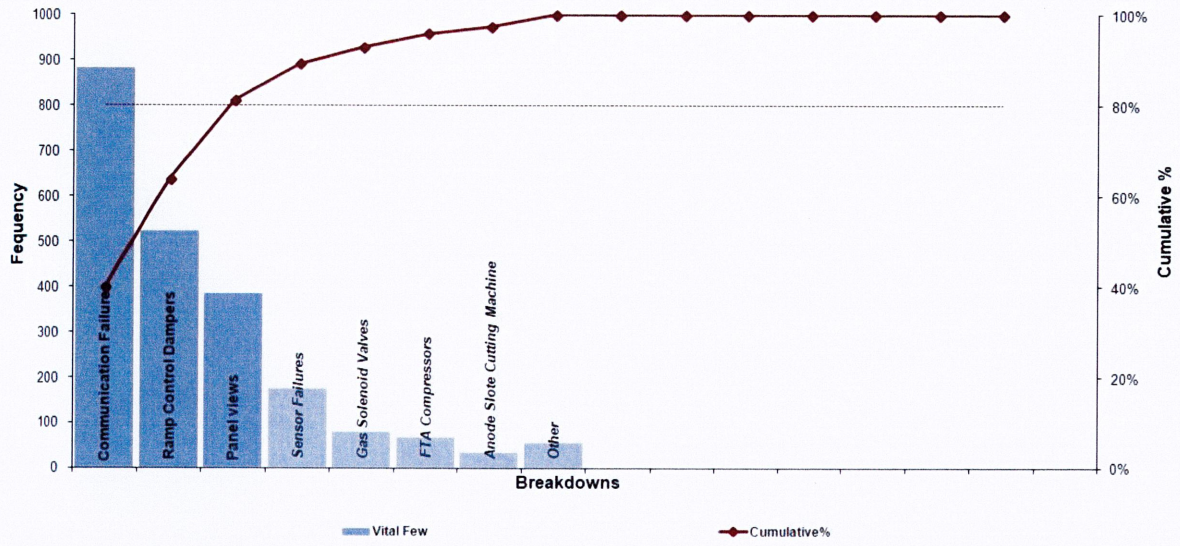


Fig. 5.11: Pareto chart for Kiln plants breakdown

The first three breakdowns represented 82% of the total number of breakdowns. The major breakdown was communication failures (40%), the second highest breakdown was the control damper of the ramps (24%), and then followed by the panel view screen breakdown (18%). It can be noticed that all the three components are part of the firing system.

An analysis was carried out with the help of the technical experts who worked in this system for more than 25 years and knowledgeable about the work environments; in order to determine the root causes of the major breakdowns that are identified above. Then, recommend an appropriate maintenance type to eliminate or reduce the potential impact of the breakdowns; in order to ensure safe and smooth process flow. The benefits of eliminating or reducing these breakdowns are that the man-hours and costs spent on maintenance will be reduced. Moreover, the IMS employees will be safe because the number of

the maintenance visits will be minimized. Hence, they will be far away from the risks of the plant.

The root causes of the major breakdowns found and summarized in Table 5.7.

Table (5.7): Root Causes of the Major Breakdowns

No.	Breakdown	Root Causes	Reason for Breakdown
1	Communication Failures	Communication cable faulty	Due to aging and mishandling by the user.
		Controller cards faulty	Due to an increase in the panel temperature and dust accumulation.
2	Ramp Control Damper	Damper lock damage	Due to the vibration while transferring the ramp and pitch accumulation..
3	Panel View Screen	Electronic card freeze	High panel temperature and dust accumulation.

Recommended Maintenance Action

The recommended maintenance actions of the major breakdowns have been provided based on the failure records and the opinion of the technical experts as follows:

Communication and Screens Failure Analysis and Recommendation

The proactive maintenance was selected to eliminate the breakdowns of communication failures and panel view screens. The predictive maintenance purpose is to monitor the panel temperature to take an action to prevent the

panel temperature from rising. The panel temperature rises due to two main reasons. The first reason is that the Air Conditioning (AC) is not functioning properly, while the second reason is from putting hot anodes beside the panel. Therefore, installing a panel temperature sensor will help the operation to monitor the temperature and an alarm can also be programmed, once the temperature of the panel exceeds the permissible limit the operators will be alerted. Once the alarm gets activated, a safe and fast action must be taken by a trained operator to make sure that the AC functions properly and there is no hot object near the panel. When these actions are taken and the issue still exists, then the maintenance team should be triggered. These inspections are defined as autonomous maintenance.

With regards the dust accumulation in the panel, preventive maintenance was selected to ensure that the panel is always free of dust. Further, the experts suggested changing the wired technology that is used for the communication with a wireless technology; in order to eliminate the breakdowns, due to the communication cable permanently.

Ramp Controller Damper Failure Analysis and Recommendation

Regarding the ramp control damper, the recommended maintenance actions were adding high quality shock absorber and weekly preventive maintenance inspections. In addition, the experts suggested an autonomous maintenance action, to solve the issue of pitch accumulation by cleaning the dampers in each fire change.

The primary outcome of implementing the recommended maintenance actions is to increase knowledge and ownership among the operation. In addition, to

minimizing the time of restoring a failed machine, thus improving the system availability. Moreover, the maintenance team will not be disturbed while performing the planned maintenance, which will achieve the main objective of the PM. Accordingly, the reactive maintenance man-hour will be minimized by reducing the number of breakdowns as well as their impacts, such as costs and safety issues which will be eliminated.

Supervisor's Support

Based on the results of the collected data, most of the employees receive support from their supervisors when the maintenance is required. The advantages of this, the employees will be more confident while executing the maintenance activities. Unconfident employees will be less productive at work and can harm themselves and others. Also, there will be benefits of sharing skills and knowledge between the senior staff and the employees, which can enhance their experience. However, the employees must get as much as possible from the benefits of the provided support; in order to be more competent at work. Since the frequent support from the supervisors could be a sign of incompetence of performing the work.

Employees' Experience

Regarding the employees' experience, it has been found that the employees have the ability to maintain all plants and equipment of the Carbon department, since their responsibilities are to maintain all plants. The positive side of maintaining the plant wide equipment is that, in case of breakdown, any of the employees who are near to the equipment can take immediate actions to normalize the equipment. In contrast, the drawback of the plant

wide maintenance is that it may cause a difficulty for the employee to be an expert on a specific equipment; in order to solve critical issues . Therefore, it is recommended to have a periodic rotation of the employees with a flexibility in the transferring of the employees when there is a need to cover other plants.

Maintenance Team Involvment

There is good communication between the maintenance department and the production department, but it does not achieve the level of trust. The relationship between the maintenance department and the production department is invaluable in any industry since both departments seek to achieve the company's objectives. The side that needs to be improved is to build a solid relationship between the maintenance department and the production department. The maintenance team must be involved in any major changes in the operation process instead of reporting them at a stage where the decision has been taken; in order to implement the required actions. These changes could affect the operations of the equipment, which may lead to unwanted situations, such as repetitive breakdowns or may cause new risks, since they did not consider the valuable experience of the maintenance crew. Furthermore, one of the benefits of building a solid relationship with the production department is that it will allow the maintenance team to get the required resources in order to accomplish their strategies.

Operation Team Training Recommendations

The operation team must be trained on the basic maintenance activities, such as the individual inspection to have the ability to differentiate between the

process problems (e.g. Actual blockage) and the instrument problems (e.g. Wrong alarm due to instrument failure). When any abnormal condition is observed by the operators, an inspection must be done before triggering the maintenance team. If it is a process problem, the operator must take a safe and fast action to normalize the process. The outcome behind this practice is that it will reduce the breakdown duration and its consequences. Another benefit is that the maintenance team will attend once there is an instrument failure where this will not disturb the IMS crew from the planned activities. Moreover, once the operators receive adequate training, their knowledge will increase, leading to improve equipment handling and ownership. Therefore, the proper equipment handling will increase the lifespan of the equipment, and reduce the probability of the repetitive breakdowns. Besides that, the trained operators will be able to report the issue accurately so that the maintenance crew has clear information about the problem. This will help the team in the preparation of the required materials, such as the spare part, tools, etc.; before conducting the maintenance work. Therefore, the failed equipment will be restored safely and quickly, thus minimizing its impact on production.

Maintenance Practices Recommendentions

Also, the study results indicated that the maintenance practices which IMS follow are mixed between corrective, preventive, and predictive maintenance. However, the predictive maintenance practices are limited due to the unavailability of adequate devices to predict the status of the equipment or machines. The existing techniques that IMS crew follow to predict the failures are traditional ways, such as noise, vibration, and heat. This will not eliminate

the breakdowns, since these techniques are used only by the experienced employees.

Immediate Maintenance Actions

Based on the data, an immediate response is taken when the breakdown occurs or equipment fails. The advantage of this action is that the availability of the plants will increase. In other words, the downtime of the equipment will reduce. In fact, the quick response to the breakdowns is required, but not at the expense of the planned maintenance activities. As agreed by the majority of the employees that the planned maintenance activities are affected when the breakdowns occur. This will reduce the effectiveness of the planned maintenance, which may cause an increase in the number of the breakdowns. Therefore, the incomplete planned maintenance should be rescheduled instead of being cancelled.

Workflow Systems

There are clear workflow systems followed by IMS on the preventive maintenance and the corrective maintenance. Where the preventive maintenance (PM) orders are released by the planning team as hard copies to be sent to the IMS supervisor and then received back to be entered into the system as completed or uncompleted PM. Whereas, the corrective maintenance orders are normally generated by the operation team through the Enterprise Resource and Planning (ERP) system to trigger the IMS supervisor and then the IMS supervisor is responsible to send one of his team in order to check and solve the problem. However, the results indicated that there is no systematic workflow followed when changes are required in the process or

equipment. The process changes mean that in some cases the process team who is responsible for the process quality will ask the IMS supervisor to adjust the instrument parameter for a specific purpose. With regards to the modification in the operational equipment, the orders generated by the plant owner which is the production team. These two processes are normally reported directly to the IMS supervisor; in order to implement the requirement. This might increase the chance of unreported changes to the planning team and reduce the man-hours that are assigned to the planned maintenance activities. Thus, this may lead to ineffective planned maintenance and irrelevant data records.

Maintenance Procedure Recommendations

In relation to the maintenance procedure, the results indicated that there is a maintenance procedure in place. However, a high percentage of employees agreed that the existing procedure is inadequate. The maintenance procedure must be written as a set of clear and detailed instructions, so that the maintenance employees can perform the task successfully from the first attempt. It also must be periodically updated, to ensure that it covers all changes or modifications happened in the workplace and ensure that it contains the best practices that are learnt by the experience. Therefore, more focus is required in the existing procedure to assure that it is explicit for all employees to be followed easily. This will help to enhance the employee's skills, especially the juniors, and to ensure that the maintenance activities are performed efficiently and effectively.

KPI Recommendations

As regards to the Key performance indicators (KPIs), ALBA has identified three major KPIs as a strategic plan to achieve the company's vision and mission. The first major KPI is related to social responsibilities which include four perspectives; namely: safety, health care, environment, and employee development. The second major KPI is about profitable growth, which focuses on the production capacity, sales, the customer's perception, and innovation. The third KPI that has a major contribution in achieving an ALBA's goal is the global competitiveness which includes two perspectives; namely: cost competitiveness, and the quality of the products. The results of the study indicated that there is a good list of KPIs used by the planning team to monitor the performance of the department. The KPIs are derived from the defined objectives that must be achieved; in order to be aligned with the vision and mission of the business. The KPIs are reviewed on a monthly basis by the planning team and the top management to evaluate the achievement of the objectives and to identify where to focus. In some cases, the head of maintenance section is invited when there is a need to focus on an area that is related to the maintenance section. The study results also indicated that the KPI reviews are not always shared with non-supervisory or non-management levels. This could lead the IMS crew to fall into the trap of focusing more on less priority work or equipment. Thus, the maintenance section heads should communicate to their teams about the latest update of the KPIs, since they are receiving the updates directly from the planning team. This will help the IMS team in each level to work effectively toward the assigned strategies in order to achieve the department objectives. Moreover, the non-management will be fully aware where to focus or the area that is linked with KPI without neglecting other areas.

Maintenance Team Training Recommendations

In relation to the training, the result shows that the training is provided to the IMS crew regarding the latest technologies, production process, operation of the equipment, and techniques and methods to analyze failures. However, the majority of the employees are unsatisfied, because it is inadequate. This finding implied that the quality of the maintenance activities during the preventive maintenance and corrective maintenance is not highly effective. Adequate training programs will enhance the employees' skills and knowledge to be more competent while performing the maintenance activities. This can increase the quality of the production, decrease the downtime of the plants, increase the awareness of the employees about the risks that are associated with the workplace to be prevented, and reduce the chance of the accidents since the employees will attend less breakdowns. Therefore, there is a crucial need to focus more on developing the training programs, spare time and money to have quick outcomes, which helps the department to meet its objectives.

Breakdown Occurrence

The result shows that the breakdown occurs daily and the main causes of the breakdowns are sometimes known. This finding indicated that the employees are solving only the observed issues without knowing the main causes of the problem. This might cause the same problem to happen again or there is a chance to cause other severe problem. Therefore, any breakdown that has unknown root cause must be reported to the supervisor to conduct root cause analysis and solve the main cause of the problem instead of the symptom. Moreover, the employees have to be trained on how to figure out the exact

root causes by themselves, while investigating the problem with the 5-Whys technique as an example, instead of fixing the problem for a day or two.

Maintenance Records

Regarding the maintenance records, the results indicate that the culture of keeping records after any maintenance work exists. However, the quality of the records needs to be improved, especially the details that are related to the breakdowns, such as stating clearly what was the problem, the action taken to solve the problem, the materials or spare parts used on the job, duration of tasks, and any relevant information. This will increase the reliability of the records; in order to be meaningful for studying any failure, which can be used to set an effective future maintenance plan. In addition, the paper records, such as spare part details should be replaced to be recorded in the system as soft copy. This will help the IMS crew to find out the required parts easily; in order to attend the maintenance work quickly.

Maintenance Team Chanllenges

Regarding the challenges that are faced by IMS, the study found out that the mean of all 11 factors ranged from 4.15 (the highest) and 3.35 (the lowest), which is above the central-neutral point. This is an indication that all 11 factors have a significant role in the IMS performance. However, it should be noticed that there were two factors perceived as the most significant with a mean greater than 4. These two factors are "lack of motivation, rewards and recognition systems " and " shortage of manpower ". This means that the IMS crew believed that these two factors play the most significant role in influencing the IMS performance.

Accordingly, the human factors, such as motivation, rewards, and recognition are the one of the most powerful elements that influences the productivity of the maintenance workers. The efficiency and effectiveness of the executed work depend on the attitude of the maintenance crew, such as creative, positive, and friendly. In fact, these attitudes will lead to a self-initiative among the maintenance crew. It will allow them to carry out the maintenance work with high morale; in order to achieve the best quality of work and accept the challenging environment of Carbon plants. Therefore, the management must turn attention to improve the current motivation strategies to be properly aligned with business objectives and ensure it includes monetary factors such as a competitive salary, incentive, and bonus. Also the non-monetary factors should be considered such as appreciation, recognition, and job grading.

Additionally, management has to give enough attention to the issue of manpower, since 80% of the IMS crew agreed that there is a shortage of manpower and this is affecting the maintenance performance. Further, the lack of trained manpower can prevent the IMS from completing the preventive maintenance activities. This will then be translated as an increase in the number of breakdowns. Moreover, when there is adequate trained manpower, the overtime hours will reduce and the IMS crew will be less stressed and alert for their safety, because the workload will be distributed among the team properly.

In addition, the management need to determine the Overall Equipment Effectiveness (OEE) for the Kiln plant in the Carbon plant department. Also,

to ensure that the OEE is benchmarked in relation to world class plants. Furthermore, it should be disseminated it to all IMS employees to share an ownership environment.

5.7 Conceptual Framework

An eight-steps framework has been tailored as a robust guideline to be appropriate to the present situation. The main feature of the proposed framework is that it can help the IMS of Carbon department to enhance the current performance, by tackling the gaps that are identified in this study. It also can ensure the continuity of IMS performance improvement, by preventing the same issues from happening again. The framework consists of eight main perspectives, as shown in figure 5.12.

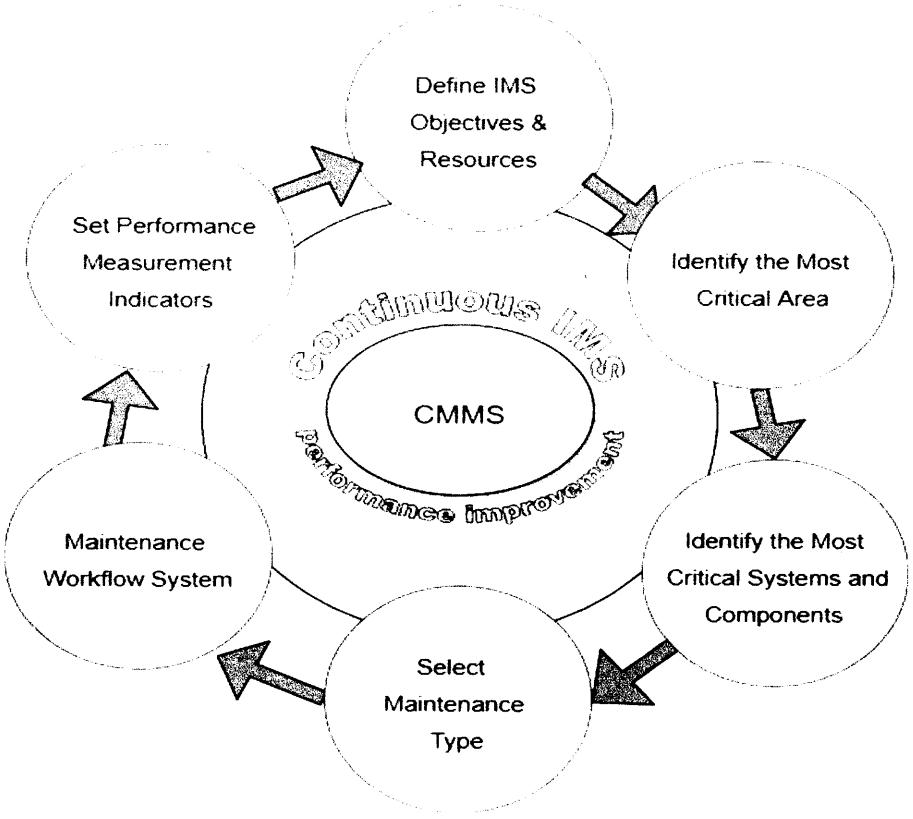


Fig. 5.12: IMS maintenance conceptual framework

1- Define IMS objectives & resources: the first step in the developed framework is defining the maintenance objectives and the resources required. The objectives will be set directly by the management of the department. The identified objectives should always be relevant to the business objectives. Furthermore, the objectives should be shared clearly to all employees, to create an ownership environment and ensure that each employee knows what must be accomplished. This will help the employees in evaluating their performance by themselves, to identify the barriers that prevent them from achieving the goals.

The established maintenance objectives must include:

a. To ensure the safety and health of the employees and the workplace.

b. To increase the reliability and availability of the production equipment.

c. To improve the maintenance skills and knowledge of the IMS crew.

d. To ensure the availability of the spares and materials when needed.

e. To build up a robust maintenance activity record.

2- Identify the most critical area: this activity involves identifying the barriers that prevent the IMS from achieving the established objectives. Number of functional failures used to identify the key bottleneck area that has the highest accumulation of breakdowns. The Kiln plant is the bottleneck to the carbon plants due to the significant increase in the number of breakdowns as illustrated in figure 4.10.

3- Identify the most critical systems and components: this activity involves applying Pareto analysis to identify the critical systems and components that have a significant impact on the Kiln plants production. It is important to the IMS crew to know the level of criticality of their systems and components, so they pay extra attention, while performing the maintenance activities; in order to eliminate or minimize the probability of the failure. In addition, once it is applied correctly and shared with the whole crew it will increase the experience among the IMS crew.

According to the case study application, the result of the Pareto analysis identified the firing system, as the most critical system; due to the repetitive breakdowns of its components. It also revealed that the bottleneck

components of the firing system are the communication failures, control damper, and panel view screens.

4- Select maintenance type: Based on the failure records and the opinion of the technical experts through a brainstorming session, the maintenance types of the bottleneck component failures were selected. Table 5.8 summarizes the maintenance types that are selected for the bottleneck components of the firing system.

Table (5.8): Maintenance Types of the Firing System

No.	Breakdown	Root Causes	Reason for Breakdown	Recommended Action
1	Communication Failures	Communication Cable faulty	Due to aging and mishandling by the user.	- Changing the design to wireless technology.
		Controller cards faulty	Due to Increase in the panel temperature and dust accumulation.	- Predictive Maintenance. - Preventive Maintenance
2	Ramp Control Damper	Damper lock damage	Due to the vibration while transferring the ramp and pitch accumulation.	- Modify the ramps to have a strong shock absorber. - Autonomous Maintenance
3	Panel View Screen	Electronic card freeze	High panel temperature and dust accumulation.	- Predictive Maintenance. - Preventive Maintenance.

5- Maintenance workflow system: it is an essential step for any maintenance department to have a clear and robust workflow system; in order to plan and schedule the maintenance tasks smoothly and effectively. Implementing the workflow of other companies is not always a right decision. The workflow system must be designed to fit the work environment and the resources available with the Carbon maintenance department. The results in this study, found there is no systematic workflow followed for handling the work orders that are raised by other departments. Therefore, developing systematic workflow will enhance the communications and the cooperation between the parties, so that maintenance activities are planned and scheduled, effectively and efficiently. The proposed workflow is shown in figure 5.13.

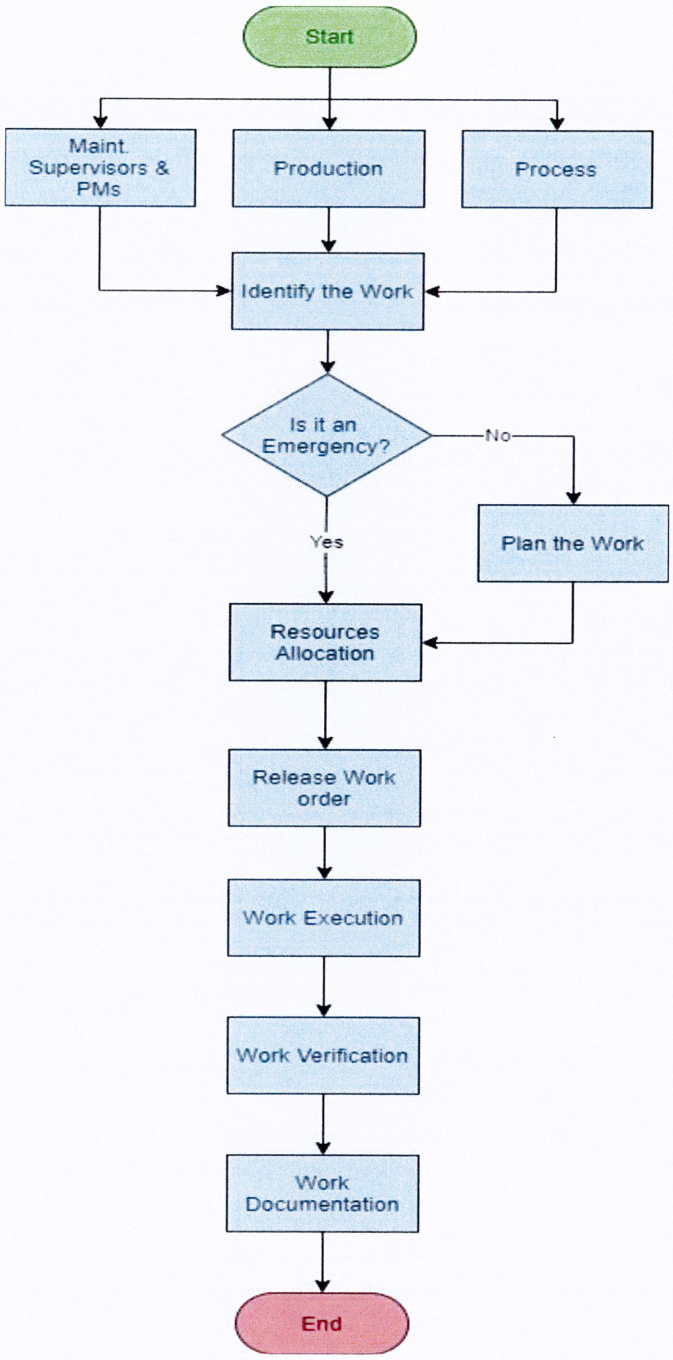


Fig. 5.13: Proposed workflow process

As shown in figure 5.13, the first action of the proposed workflow process is that the work orders can be issued by the maintenance supervisors and PM

checklists or by the heads of the production or the process department. The work order request should be done through the ERP system, to ensure that all orders are documented.

The second action, once the work order request is issued it will be received by the head of the maintenance department and planning team. The request then will be discussed with the supervisors; in order to study and evaluate the request. Once the request is technically applicable and necessary, it will be prioritized based on the nature of the risk that is associated with the request and the deadline. If the request is related to an urgent case, the resources required will be allocated by the planning team immediately and then release the work order to the IMS supervisor to be executed. If the request is not an emergency case, the work will be planned.

The third action is related to the work order execution, during the work execution the planner has to follow with the supervisor, to ensure the progress of the work is executed as planned, and evaluate its quality.

Finally, the planning team must ensure that all completed work orders are documented. This will help to build a relevant historical data about the machines and performance. It will also assist the management to take the right decisions.

6- Set performance measurement indicators: the aim of the selected key performance indicators that are listed below in Table 5.9 is to monitor the actual tendency of the IMS performance toward the maintenance objectives:

Table (5.9): Recommended KPIs

No.	Maintenance KPI	Target/ Baseline
1	Proactive Maintenance Work (man-hour)	>= 85 %
2	Reactive Maintenance Work (man-hour)	=<5 %
3	Modification/ Redesigning Work (man-hour)	>= 10 %
4	Schedule Attainment	> 95 %
5	Manpower Utilization	> 95 %
6	PM Compliances	> 95%
7	PM Delayed (due to lack of manpower or materials)	< 2%
8	Breakdown Notification Outstanding	< 5 %
9	Maintenance Cost per MT	14.582 BD/MT
10	Overall Equipment Effectiveness (OEE)	> 85%

7- Computerized maintenance management system (CMMS): The company is using an Enterprise Resource Planning (ERP) system from SAP, which stands for Systems Applications and Products. All maintenance activities are recorded in this system, such as failure information details, duration of breakdowns, the actions taken to restore the failed machines and equipment. Then the collected maintenance data will be converted into meaningful reports with no time to facilitate the data analysis process. Further, it will have all the information required to measure the IMS performance easily.

8- Continuous performance improvement: All the framework perspectives that are discussed above must be interconnected with the CMMS and integrated with each other as a loop to achieve the optimum IMS performance and ensure they are always in the improvement track. The established maintenance objectives and its KPIs should be always in clear for all IMS crew; in order to ensure it is continuously aligned with the business objectives, and to monitor and evaluate the progress against the known objectives over all time. Using KPIs, the performance of the plant can be measured in terms of the Overall Equipment Effectiveness (OEE). The results of the performance measurement will lead to an improvement in all areas, such as updating the established objectives, improving the most important system and its bottleneck component, choosing the best maintenance type, and improving the workflow systems and the data of the CMMS.

The proposed framework will assist the company in eliminating or minimizing the breakdowns so that the availability of the process machines and equipment will be increased. This will help in improving the speed and quality of the production at the minimum cost. One of the most important benefits of this framework is that it will help in eliminating the risks that are associated with the workplace to ensure employees' safety and health. In comparsion with the other pervious frameworks, the main advanteges of the developed framework are that it is simple to understand and easy to be implemented by all employees regardless their experience and educational background. Moreover, by implementing the developed framework successfully can reduce the reactive maintenance cost by 80%.

5.8 Conceptual Framework Validation

A focus group meeting was conducted with the manager and the head of maintenance and two technical and maintenance experts, to review the developed framework. During the meeting, many points have raised, including the feasbilty and relavance of the developed framework in order to identify what are the areas that need to be impoved in the framework. All participents stated that the developed framework was feasible and relevant, because it addressed the research problem effectivlly. However, there was a suggesstion to implement a minor modification on the framework. It has been suggested to add PM as a source of work order, because during the PM activities, there will be a chance of finding damage parts which need major repair.

Chapter Six

Conclusion and Recommendation

6.1 Conclusion

6.2 Recommendation

6.3 Limitation

6.4 Future Work

6.1 Conclusions

The purpose of this study was to develop a conceptual maintenance framework to improve the performance of the maintenance sections. The Instrument Maintenance Section (IMS) at the Carbon department of ALBA has been selected as a case for this study. To do so, the present Instrument Maintenance Section (IMS) practices had been investigated as a viewpoint of both non-supervisory and supervisory levels; in order to have a solid picture about the current practices from all aspects of maintenance. Moreover, to identify the existing gaps between the IMS practices and the best world class practices. Then, the main factors that are influencing the IMS performance have been identified to help the IMS management to ensure putting more effort on them to boost the sections' performance. According to the data that are collected in this study, most of the employees agreed that the shortage of manpower and lack of motivation, recognition and rewarding systems are the main factors that affect the IMS performance.

The study also found that the total IMS man-hours are distributed over three maintenance approaches, namely proactive, reactive and modification or design improvement maintenance. However, the reactive maintenance man-hours show that they increased rapidly over the studied periods, which affect the proactive maintenance man-hours. As most of the employees agreed that the daily breakdowns are affecting the proactive maintenance plan. Furthermore, the Kiln plants were found to have the highest portion of the reactive maintenance; due to the repetitive failures in the firing system. By

using Pareto chart, it was found that three repetitive breakdowns play a vital role, which led the total number of breakdowns of the Kiln plants to increase. These breakdowns are considered as a bottleneck component for the firing system. With the help of the technical experts, a brainstorming session was done and the root causes of the bottleneck component failures were identified. Then, different maintenance practices were selected to eliminate the breakdowns in the bottleneck components; in order to reduce the percentage of the reactive maintenance and ensure the proactive maintenance plan intended as scheduled.

To ensure the efficiency and the effectiveness of the developed maintenance framework, an intensive review was carried out to the literature that is related to maintenance strategies, maintenance tools and techniques, maintenance performance measurement, and five different maintenance frameworks. The developed framework consists of eight steps. The first step is about defining the maintenance objectives and the required resources. The identified objectives are relevant to the business objectives. The second step is identifying the barriers that prevent the IMS from achieving the established objectives. The most critical area was identified by using the number of functional failures. The step block is identifying the most critical systems and components by using Pareto analysis; in order to pay extra attention while performing the maintenance activities. The next step is selecting the suitable maintenance types for the bottleneck components by considering the opinion of the technical experts. The fifth step is developing a systematic workflow to enhance the communication and the cooperation between the parties that are involved in the maintenance activities. Sixth step is setting the performance management indicators to monitor the actual IMS performance with respect

to the identified objectives. The seventh step is interconnecting all the previous steps with the CMMS; in order to have detailed records of all maintenance activities and generate meaningful reports to assist in evaluating the IMS performance. The final step is monitoring and evaluating the IMS performance continuously to ensure that the improvement area is always addressed.

By implementing the developed framework correctly, the management will ensure that the IMS crew follows proactive maintenance to take its benefits and reduce the percentage of the reactive maintenance to avoid its consequences. Therefore, the IMS crew and the production equipment will be in safe condition. The production losses, due to the repetitive failures will be eliminated. Furthermore, the moral of the IMS crew will increase so that they will always think creatively to improve maintenance practices and the production processes. Thus, the reliability and availability of the equipment will be enhanced through its life span. In this study, the importance of maintenance and its role and impact on business has been investigated. It can be summarized as, maintenance is considered as a profit center in the successful organization while it is considered as a cost center in unsuccessful organizations.

6.2 Recommendations

According to the results that are found in this case study, the management of the Carbon department recommended to consider the following points, in order to ensure that the performance of IMS crew are effective and efficient when performing the maintenance activities.

- Implement the maintenance management framework to ensure the IMS performance is always in the continuous improvement cycle.
- Upgrade the maintenance practices that are applied in the firing system in order to minimize the total number of breakdowns in Kiln plants.
- Share and Update all IMS crew with the Key Performance Indicators (KPIs) to build an ownership culture among all the team.
- Measure the Overall Equipment Effectiveness (OEE) to reduce the downtime of the production equipment.
- Train the operation and IMS crew on writing accurate and detailed maintenance reports on CMMS software to ensure the reliability of the recorded data.
- Increase the number of the employees of the IMS team to prevent any temporary solutions and to ensure the preventive maintenance is completed efficiently and effectively.
- Improve the current motivation strategies to include monetary and non-monetary factors to boost the self-initiative among all maintenance crew and achieve best quality of work.
- Implement the systematic maintenance, workflow to enhance the communication and the corporation between the departments to ensure that the maintenance activities are planned and scheduled effectively and efficiently.

6.3 Limitation

In this research, there are many encountered limitations while carrying out the study:

- The first limitation of this research study is that it is limited to Carbon Department in ALBA. However, it is possible to adopt the results in other departments of ABLA due to the similar work environment and policies.

- The second limitation is the lack of previous studies about the same research topic in Aluminum smelters. Therefore, the researcher referred to previous studies in other industrial manufacturers.

- The third limitation is the difficulty to access some historical data because of the absences of participants from planning department due to the Covid 19 epidemic. Therefore, the researcher filled the gap by collecting data from the head and supervisor of the maintenance department, based on their long experience of previous events.

6.4 Future Work

This research indicates that there are some recommendations for the researchers who are interested to pursue more research in the same domain. These recommendations are summarized as follows:

- It is recommended to conduct this study in all maintenance departments of ALBA. The developed framework could be changed according to the addressed problems.

- It could be interesting to determine empirically to what extent the breakdowns duration affects the operational performance.

- Study the affect of integrating the existing CMMS with the AI and IOT for process monitoring and control, reporting and documentations.

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Appendices

Appendix (1):

Questionnaire Surveys:

Open-close ended questionnaires used to collect the necessary information from non-management level.

Part 1: Introduction Letter

Request For Cooperation in Research Data

I am a postgraduate student at the University of Bahrain in college of engineering. I am currently conducting research on the Instrument Maintenance section at Carbon department entitled "Improvement of Maintenance Performance of the Instrument Maintenance Section at the Carbon Department of ALBA". The purpose of this study is to highlight the current maintenance practices and identify the main factors that influence the performance of the Instrument Maintenance Section (IMS).

In this respect, you have been selected to take a part of this study. This is to kindly request your cooperation in answering this questionnaire as accurately and honestly as possible. The data generated from this study will be used as the basis of this thesis, which will be shared with the University of Bahrain.

Please be notified that being a participant in this study will not cause you any risks. Your identity will be anonymous and all your provided answers will be at the utmost confidence.The data will be used for academic purposes only. However, it is assumed that this study will enhance our understanding of concerns and matters related to maintenance management practices.

Thank you very much for your time. Your efforts are highly appreciated.

Yours faithfully,

Part 2: Preliminary Information.

1- What is your position in Aluminum Bahrain (ALBA)?

2- What is your age?

a) From 20 - 30 years b) 31 – 40 years c) 41 – 50 years d) above 50 years

3- How many years of experience do you have?

a) Less than 3 years b) 4- 10 years c) 10 - 15 years d) above 15 years

4- What is the highest educational qualification you have attained?

a) Diploma b) Bachelors c) Master d) Other.....

5- How would you rate the operational performance of the Carbon department?

a) Very good b) Good c) Average d) Poor e) Very poor

Part 3: Present Maintenance Practices

How would you rate the following maintenance practices in the Instrument Maintenance Section (IMS)?
Please indicate the practices with the following statements: 'Always', 'Most times ', 'Sometimes', 'Rarely' and 'Never'.

No.	Practice	Always	Most times	Sometimes	Rarely	Never
1	Main causes of repetitive failure are known					
2	Breakdowns occur daily					
3	Immediate action is taken on sudden breakdowns (unplanned breakdowns)					
4	Planned maintenance activities affected when breakdowns occur					
5	Failures recognized before it occurs					
6	Receiving support from the supervisors when performing the maintenance activities					
7	Proper tools used to perform the maintenance activities					
8	Tools kept in the proper place					
9	Availability of spare parts when needed					
10	Spare parts stored in the proper location					
11	Inventory managed and controlled efficiently in the warehouse					
12	Commitment with safety procedures					
13	Keeping records for any projects, modification or redesigning work.					
14	Involving in operational projects, equipment modifications, and process changes.					
15	Receiving adequate training in the production process and operation.					

16	Receiving adequate training on the latest technologies to improve the maintenance activities.					
17	Receiving training in methods, techniques and applications to assist in the failure analysis.					
18	Safety of manpower and environment issues are controlled.					
19	Sufficient resources allocated for planned maintenance activities.					

1- Are there adequate maintenance procedures in place?

a) Yes b) No

2- Is there clear training schedule plan?

a)Yes b) No

3- Are the key performance indicators analytic shared with you?

a) Yes b) No

4- Select the nature of the failures of the firing system at Kilns plant? (More than one failure can be selected). Please mention the percentage of failure occurrence for each.

√	Nature of failures	Percentage of occurrence (%)
	Cables	
	Batteries	
	Screen	
	Controller Cards	
	Power Supply	
	Network Switches	
	Others	

5- What are the main causes of the repetitive failures? (More than one failure can be selected). Please mention the percentage of failure occurrence for each.

√	Main causes	Percentage of occurrence (%)
	Vibration	
	Heat	
	Insufficient preventive maintenance	
	Improper equipment handling	
	Minor faults ignorance	
	Others	

6- What is the technique used to recognize the failure?

7- What do you recommend to solve the repetitive failures?

8- What are the maintenance practices in the IMS Carbon Department?

Part 4: Challenges of Maintenance Performance

To what extent the following factors influence the Instrument Maintenance Section (IMS) performance?
Please indicate the factors with the following Liker Scale 1 to 5 points: 5 points being "Strongly Agree", 4:'Agree', 3: 'Neither Agree nor Disagree', 2: 'Disagree', and 1: 'Strongly Disagree'.

No.	Factors	Strongly Agree	Agree	Neither	Disagree	Strongly Disagree
1	Shortage of manpower					
2	Lack of required spare parts					
3	Lack of training					
4	Lack of proper tools for maintenance jobs					
5	Lack of motivation, rewards and recognition systems					
6	Lack of skills and knowledge					
7	Lack of management support					
8	Lack of documenting the maintenance work					
9	Lack of involvement in management decisions					
10	Absence of new technologies for maintenance jobs					
11	Misuse of effective maintenance practices (proactive, condition-based maintenance, RCM, TPM)					

Appendix (2):

Interview Questions

Part 1: Maintenance Planning

1- Is there a planning system for your maintenance activities? If Yes, How frequently is it?
2- How is the maintenance plan selected?
3- Are the maintenance activities recorded after execution of the maintenance tasks?
4- Are maintenance tasks evaluated after recording them?
5- What current workflow system does IMS follow?

Part 2: Performance Measurement

1- What type of key performance indicators (KPIs) do you use?
2- How KPIs are selected and how frequently reviewed?
3- Are the KPIs' reviews shared with all IMS crew?
9- Are Overall Equipment Effectiveness (OEE) determined for Carbon Department, and how are they calculated?
10- How do you review the maintenance objective appropriates with key performance indicators?

Part 3: Maintenance Management

1- Are Maintenance activities considered as a strategic factor in developing the department?
2- Does top management support you?
3- Is there a good communication between maintenance and production department?
4- Does the production department ensure the full utilization of plant assets?
5- Are employees involved in management decisions?
6- Is the operation team involved in the basic maintenance work?
7- Does management support continuous improvement in maintenance practices?
8- Is there a particular method or tool conducted to find the root causes of the repetitive failures?
9- How do you review the maintenance strategy alignment with the maintenance objective?

Appendix (3):

Present State and Maintenace Factors Analysis

Part 1: Man-hours available for maintenance activities

Year	Proactive Maintenance (Man-hours)	Reactive Maintenance (Man-hours)	Modification Work (Man-hours)	Total (Man-hours)	Proactive Maintenance (%)	Reactive Maintenance (%)	Modification Work (%)
2014	20,599	2,897	793	24,289	85	11.9	3.3
2015	22,318	5,984	338	28,639	77.9	20.9	1.2
2016	22,728	5,376	1,049	29,152	78.0	18.4	3.6
2017	22,200	6,598	193	28,990	76.6	22.8	0.7
2018	28,628	8,120	321	37,069	77.2	21.9	0.9

Part 2: Total number of the communication failures

Year	Total Kiln Plant Breakdowns	Communication Failures	% Communication Failures
2014	1409	328	23%
2015	1442	329	23%
2016	1313	327	25%
2017	1939	521	27%
2018	2205	883	40%

Part 3 (a): Factors affecting maintenance performance

No.	Factor Description	SA	A	N	D	SD	Mean
1	Shortage of manpower	35	45	10	10	0	4.05
2	Lack of required spare parts	20	40	20	20	0	3.60
3	Lack of training	25	45	10	20	0	3.75
4	Lack of proper tools for maintenance jobs	15	35	20	30	0	3.35
5	Lack of motivation, rewards and recognition systems	50	25	15	10	0	4.15
6	Lack of skills and knowledge	25	50	15	10	0	3.90
7	Lack of management support	15	40	20	20	5	3.40
8	Lack of documenting the	10	55	25	10	0	3.65

	maintenance work						
9	Lack of involvement in management decisions	10	60	10	15	5	3.55
10	Absence of new technologies for maintenance jobs	5	65	20	5	5	3.60
11	Misuse of effective maintenance practices (proactive, condition-based maintenance, RCM, TPM)	15	50	25	5	5	3.65

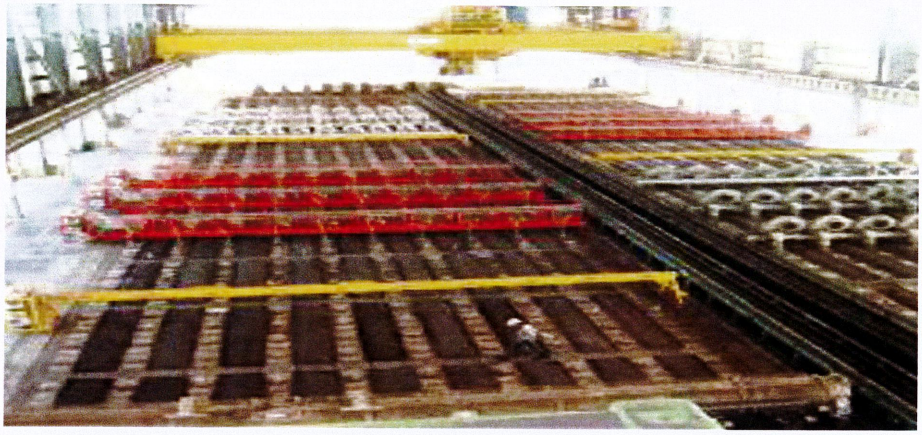
Part 3 (b): Ranking of Factors Affecting Maintenance Performance

No.	Factors	Mean	Rank
1	Shortage of manpower	4.05	2
2	Lack of required spare parts	3.60	6
3	Lack of training	3.75	4
4	Lack of proper tools for maintenance jobs	3.35	9
5	Lack of motivation, rewards and recognition systems	4.15	1
6	Lack of skills and knowledge	3.90	3
7	Lack of management support	3.40	8
8	Lack of documenting the maintenance work	3.65	5
9	Lack of involvement in management decisions	3.55	7
10	Absence of new technologies for maintenance jobs	3.60	6
11	Misuse of effective maintenance practices (proactive, condition-based maintenance, TPM)	3.65	5

Appendix (4):

Overview of the Furnace Fring System

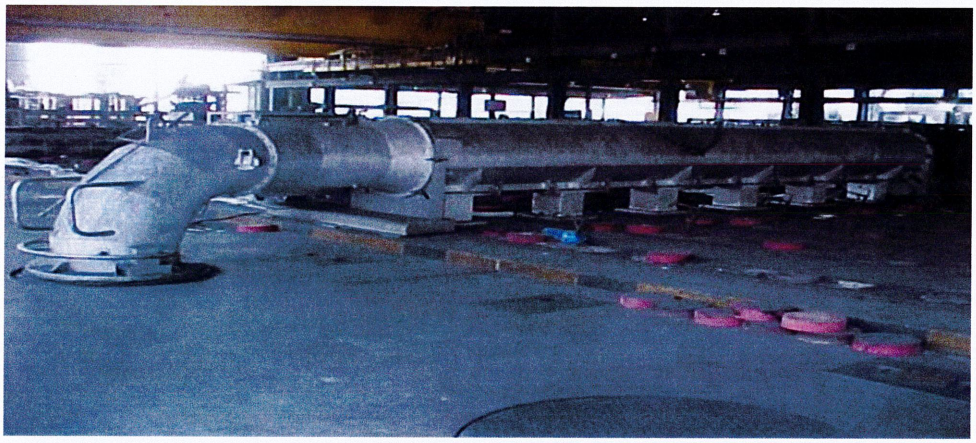
Part 1: The equipment of the furnace firing system



Kiln plant overview



Anode pit of Kiln plant



Exhaust ramp



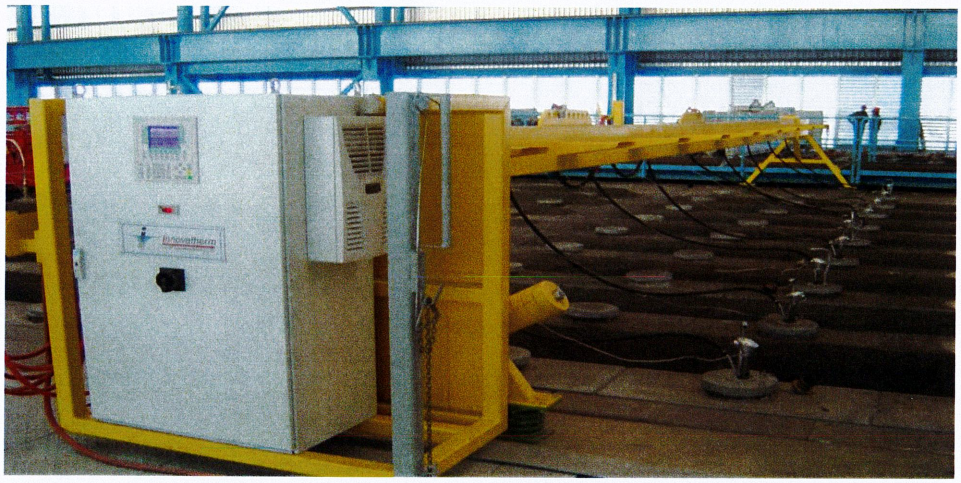
Burner ramp



Cooling ramp (Innovatherm website)



Blower ramp (Innovatherm website)



Measurement ramp (Innovatherm website)

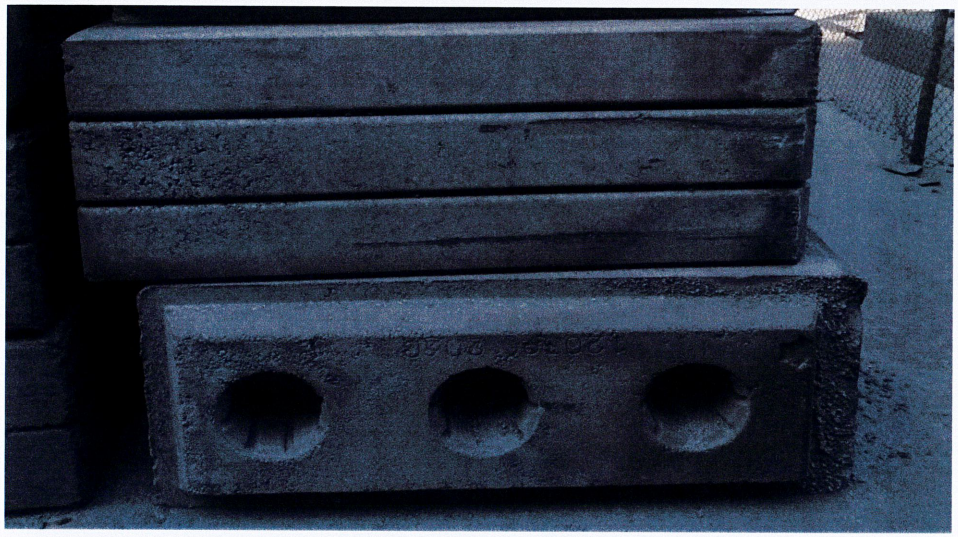


Zero point ramp

Part 2: Defective anode due to low baking quality



Defective anodes



Defective anodes

Abstract (Arabic)

ملخص البحث

أصبحت الصيانة في الآونة الأخيرة عنصرًا رئيسيًا في أي مؤسسة تسعى إلى الحفاظ على قدرتها التنافسية في السوق. وبسبب العولمة والتصنيع، زادت المنافسة بين المؤسسات المختلفة مما أدى إلى اعادة النظر إلى إدارة الصيانة واتخاذها إحدى العوامل الإستراتيجية المهمة لتحقيق الأداء الأفضل. ولهذا أجريت العديد من الدراسات في الشركات الصناعية خصوصا في البلدان المتقدمة حول إطار إدارة الصيانة. ولكن لا توجد دراسات حول هذا الموضوع في شركات انتاج الألمنيوم. ومع ذلك، فإن هذه الدراسة تناولت كيفية إدارة الصيانة في إحدى الشركات العالمية لإنتاج الألمنيوم وهي شركة ألمنيوم البحرين (ألبا). ويهدف هذا البحث إلى دراسة وتحسين أداء دائرة صيانة الأجهزة الدقيقة لقسم الكربون لتحقيق ما تصبو اليه الشركة بأقل وقت وتكلفة ممكنة. لقد تم استخدام العديد من الأساليب لجمع البيانات في هذه الدراسة، مثل مراجعة الدراسات السابقة ذات الصلة وعمل الإستبيانات والمقابلات مع الموظفين في قسم صيانة الأجهزة الدقيقة. إن هذه الأساليب ساهمت بشكل كبير في التعرف على أهم الفروق في الأداء لدائرة صيانة الأجهزة الدقيقة لقسم الكربون ومعيار أداء الصيانة في أفضل الشركات الصناعية عالميا. لقد ساهمت هذه الأساليب ايضا في تحديد العوامل الرئيسية التي تؤثرعلى اداء دائرة صيانة الأجهزة الدقيقة وترتيبها وفقا لنتائج الإستبانة. وبناء عليه لقد تم تطوير إطارعمل لإدارة الصيانة مكون من ثماني محاور لتحسين أداء دائرة صيانة الأجهزة الدقيقة. باتباع الإطار المطور وتطبيق التوصيات المقترحة في هذه الدراسة، سيتم تقليل العدد الإجمالي للأعطال ونتائجها بنسبة 82٪.

جامعة البحرين

كلية الهندسة

قسم الهندسة الميكانيكية

تحسين أداء دائرة صيانة الأجهزة الدقيقة لقسم الكربون في شركة ألمنيوم البحرين (ألبا)

أطروحة مقدمة كجزء من متطلبات الحصول على درجة الماجستير في **الإدارة الهندسية**

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مملكة البحرين

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