INVESTIGATION INTO THE EFFECTS OF PLANNING AND SCHEDULING: A CASE OF ANVIL MINING CONGO SA, ELECTRICAL ENGINEERING SECTION

By

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A dissertation submitted to the University of Zambia in fulfilment of the requirements for the degree of Masters of Engineering in Engineering Management

THE UNIVERSITY OF ZAMBIA, LUSAKA

2022

APPROVAL

This dissertation by Christian NGOIE KIYANGA has been approved in fulfilment of the requirements for the award of the degree of Masters of Engineering in Engineering Management at the University of Zambia.

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DECLARATION

I, Christian NGOIE KIYANGA, do hereby declare that this dissertation is the result of my investigation and research, and that, it has not been submitted in part or full for any degree to any other university, except where stated otherwise by reference, acknowledgement or as a requirement for the acquisition of the same degree.

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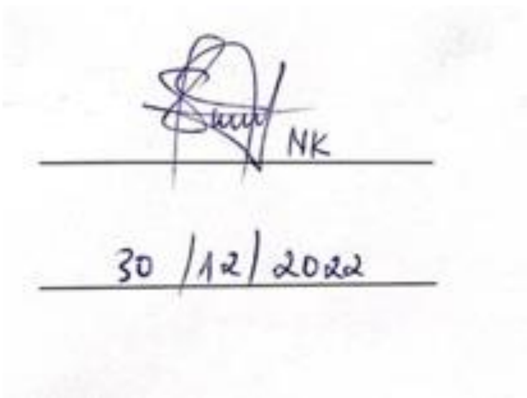

CERTIFICATION

This is to certify that this research entitled "Investigation into the effects of Planning and Scheduling: a case of Anvil Mining Congo SA, Electrical Engineering Section" was carried out by Christian NGOIE KIYANGA in the School of Engineering at the University of Zambia for the award of Masters of Engineering Degree in Engineering Management.

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ABSTRACT

In any company, the planning and scheduling process is unavoidable. This research investigated its effects in the electrical section of Anvil Mining Congo SA. In this company, the focus of planning and scheduling, particularly on equipment, is on preventative maintenance rather than actions such as repair, replacement, and installation. This research aimed to evaluate the changes in the performance of the electrical engineering section which currently lacks the daily planning and scheduling process. The research used a quantitative approach with observations and desk study as instruments for data collection. The data that was collected included the duration (time) and the human resources allocated to particular activities. Data with and without daily planning and scheduling were compared to evaluate the changes in the section's performance over a study period of 30 months. After implementing the daily planning and scheduling process, the total duration to complete works of the analysed activities was reduced by 44% while the human resources allocated to the activities were reduced by 43%. The efficiency of the section increased from 73% in December 2019 and 83% in December 2020 to 96% in December 2021. The preventive maintenance backlog reduced from 57% in January 2019, 54% in January 2020 and 59% in April 2021 to 3% in December 2021. The company's electrical section is currently implementing a pilot planning and scheduling process after which a decision will be made on whether to switch to full-scale implementation or not.

***Keywords**: Planning; Scheduling; Backlog; Efficiency; Human Resource.*

ACKNOWLEDGMENT

I am grateful to God Almighty, who knows everything and was aware of my project before it began, for keeping me alive and well enough to carry out his purpose for my life. Throughout the journey of writing this dissertation, I have received a great deal of support and assistance.

I would first like to thank my supervisor, Dr. Terence Malama, whose knowledge was indispensable in establishing the guidelines and setting limits for this research. His comments motivated me to work harder and achieve this level of excellence in my work. And my co-supervisor, Dr. Kondwani Simukonda, who always had time to discuss and review my work despite other commitments. For their contributions and inputs in my education, I would want to express my gratitude to all of the teachers from the Agricultural Engineering department and the entire School of Engineering at the University of Zambia.

I would also like to thank Anvil Mining Congo SA for letting me do my research and collect data in their plant throughout my internship. Without them, this research would have been theoretical and pointless. I acknowledge assistance from the maintenance Manager Danny Kabinga and all teams in the maintenance department of Anvil Mining Congo SA, for their wonderful collaboration during my internship. A special thanks to my internship supervisor, Papy Kalume, Electrical engineering Superintendent, for his patience and guidance on-site to conduct my research. It would be unfair of me to end these acknowledgements at the company without thanking the planner's team that became a family: Joseph, Modeste, and Jeannine: Thank you!

In addition, I would like to thank my parents Jean and Josephine and my sisters Nicole, Daulene, Jeannine, Graciaa, Syntyche, and Keren for their wise counsel, spiritual and financial support. Finally, I could not have completed this dissertation without the support of my friends Gloire, Alex, Corneille, Jules, Nehemiah, Pathie, Robert, and Darchinie who were stimulating discussions as well as happy distractions to rest my mind outside of my research. Thank you guys!

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DEDICATION

I dedicate this dissertation work to my father Jean NGOIE KIYANGA, a hardworking man, for all your sacrifices in my life. You have supported me since the beginning when I could not even believe in becoming who I am. You trusted me and my capacities. Here is the result of your trust and investment in me. May God keep you long for me so that you can see all the fruits of your sacrifices.

ACRONYMS

AMC: Anvil Mining Congo SA

PdM: Predictive Maintenance

PM: Preventive Maintenance

PPE: Personal Protection Equipment

RCM: Reliability Centered Maintenance

RM: Reactive Maintenance

CHAPTER ONE: INTRODUCTION

1.1 Background

Planning and scheduling are important in the whole industrial world. When it comes to tasks like maintenance, investment, recruitment, and so on, they are among the first actions taken.

Planning involves establishing the organizational objectives and deciding what actions need to be taken to achieve them. Many organizations write a mission statement that outlines their goals and serves as the foundation for all planning processes (Desenzo et al., 2016). After establishing the organizational objectives, the scheduling step follows. The process of assigning tasks to be completed and allocating resources according to a budget is referred to as scheduling. Scheduling as defined by Pinedo (2008) is the allocation of resources to tasks over given periods to optimize one or more objectives. It is a decision-making process that is used regularly in many manufacturing and services industries.

By offering a better understanding of the process, the planning and scheduling process minimizes or eliminates uncertainties, enhances efficiency, facilitates process management, and focuses on objectives (Project Management Institute, Inc., 2008). The planning and scheduling process in the mining industry enhances resource utilization to ensure that resources are utilized efficiently (Bruton & Lumen, 2017); and brings motivation to employees because when they know what is expected from them, they will be more involved in the planning processes.

In this study, the attention was focused on the planning and scheduling process in the Electrical engineering section which is under the Maintenance Department in a mining company called ANVIL MINING CONGO SA (AMC) in the Democratic Republic of Congo (DRC). Electrical engineering is a discipline of engineering that works on a wide range of components, devices, and systems and deals with the technology of electricity (Lucas, 2014). Electricity is employed as a source of energy for practically all modern machinery used in the mineral ores transformation process, hence this section is vital in mining companies.

For AMC, the Electrical engineering section is important because the company does not get power from any external electricity supply network. Instead, it produces its electricity from generators that supply the whole plant. These generators and all the machines that transform ore need to be kept in good working condition through maintenance activities such as parts replacement, installation and repairing. Inefficiencies in this section have serious implications in the production process. The success of all these activities depends in one way or another on the planning and scheduling process.

Maintenance is considered as a tool to reduce unnecessary job delays through preparation as reported by Palmer (2019) since it helps to walk in the future and see what will be needed and when exactly so that it can be provided and taken into consideration in the present. As a result, the planning and scheduling process is critical for AMC, not only because it affects all employees, independent of their position, but also because the future is unknown. When new information is known about the future, plans and schedules are reviewed and updated accordingly (Bwalya, 2020).

The planning and scheduling system at AMC, maintenance department, is currently operational and provides benefits to other sections of the company. However, its impact on the other sections is limited because it is more focused on preventive maintenance (PM) and predictive maintenance (PdM) activities. Hence certain activities, except those on preventive and predictive maintenance, are not planned and scheduled. Activities such as installation of new machinery, old machinery repairing, and so on, are neither planned nor scheduled. The planning and scheduling system in place considers both long and short-term activities though the focus is more on the long-term activities. This affects the progress of the activities planned and the section's performance.

1.2 Statement of the problem

The primary goal of any firm or business is to produce money and grow the wealth of its stakeholders (Pettinger, 2019). As in any other production-based company, in a mining company, unplanned machine breakdown leads to loss of production which translates to a loss of revenue. Therefore, shutdowns are planned and scheduled in advance to maintain important machines in good operating conditions.

Lack of daily planning and scheduling in the Electrical engineering section affects the PM activities. Because of unforeseen activities in the section, which may necessitate the shutdown of critical machines, the PM plans and schedules are affected. And this effect is translated into backlogs in the PM compliance. The section records reveal a backlog of 59 per cent of the PM activities for April 2021 which was the last month before this study took place. However, the standard of world-class maintenance is to achieve at least 90 per cent compliance, meaning less than 10 per cent of backlogs (Weber & Thomas, 2005). The percentage of backlogs below world standards has been persistent for a long time, indicating inadequate PM backlog management.

The efficiency of the Electrical engineering section is also affected by the lack of effective planning and scheduling because only a few activities are done among those which are supposed to be done. The section records reveal an efficiency of 83 per cent for April 2021 while the world standard of maintenance shows that it should not be less than 90 per cent (Weber & Thomas, 2005).

In other words, the lack of planning affects the performance of the section in the way that it finds itself unprepared concerning tools to be used when it comes to executing a certain activity that was not planned or scheduled. This results in more time spent on the activity than would be the case if there was prior planning.

Hence, this study was focused on the planning and scheduling process of short-term activities (that is, installation, repairing, and replacement) in the Electrical engineering section of AMC in order to assess its effects on the section. Currently, the section does not utilize short-term planning.

1.3 Objectives

1.3.1 General Objective

The general objective of this study was to assess the effects of planning and scheduling in the Electrical engineering section within a mining company.

1.3.2 Specific objectives

To achieve the general objective, the study carried out three (3) specific objectives which were:

i) To review the maintenance planning and scheduling approaches that are used in the mining industry,
ii) To evaluate the maintenance planning and scheduling system in the Electrical engineering section of AMC.
iii) To determine the effects of daily planning and scheduling system on the performances of the Electrical engineering section of AMC.

1.4 Research questions

To achieve the objectives of the study, the following questions were to be answered:

(1) How are planning and scheduling done in general and in the mining industry in particular?
(2) How are planning and scheduling done at ANVIL MINING CONGO SA?
(3) How do planning and scheduling affect the performance of the Electrical engineering section of ANVIL MINING CONGO SA?
(4) How can daily activities in Electrical engineering be planned and scheduled?
(5) What are the effects of the planning and scheduling process on the preventive maintenance activities?

1.5 Significance of the study

The information generated from this study would be helpful to the mining companies such as ANVIL MINING CONGO SA to improve the performance of Electrical engineering sections and hence the companies' maintenance departments. The information would also be valuable to other students or researchers who would want to explore more about planning and scheduling.

1.6 Limitation of the study

This study was done in the Democratic Republic of Congo (DRC) because it is one of the countries known for its mineral resources (Migiro, 2018). Despite the fact that the country has several mining companies, the investigation concentrated on AMC, which is located in the Pweto district. An aerial view of the plant is shown in Figure **1.1** and more pictures are found in Appendix **A**. Only the Electrical engineering and planning sections of the company were studied.

Though the planning and scheduling process involves many aspects, the investigation into the effects of this process considered only four (4) aspects: the duration of activities, the human resource allocated, the backlog of the PM compliance, and the efficiency of the section. Some of the documents consulted were kept as private properties of the company and were therefore not cited in this research.

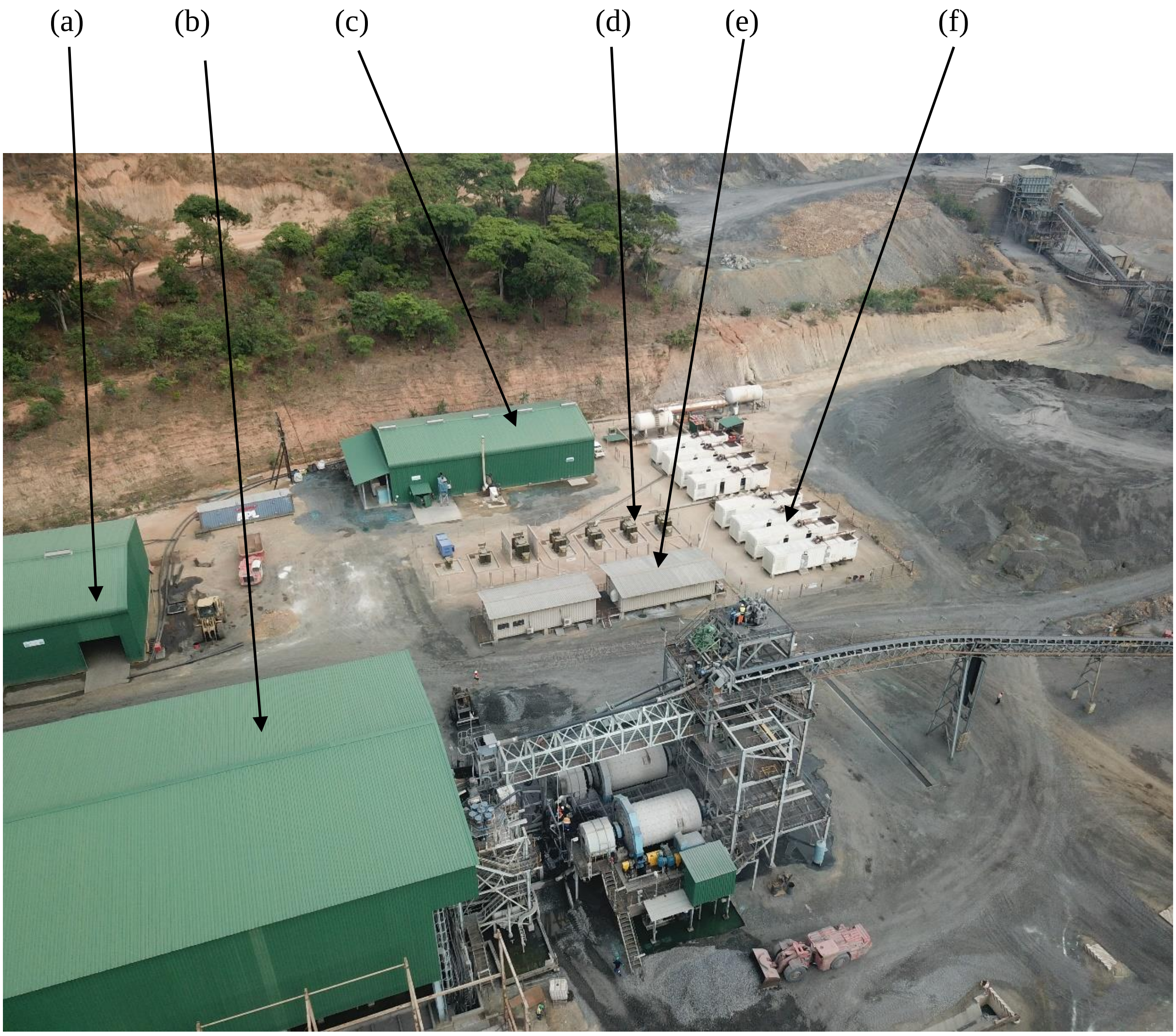

Figure 1. 1. Aerial view of the site

Key:

(a) : Mechanical workshop
(b) : Flotation Hall
(c) : Electrical Workshop
(d) : Transformer 0.4/11 kV
(e) : Main Substation
(f) : Generator 400V/ 1250 kVA

1.7 Ethical considerations

In this study, ethical considerations were considered as shown on the ethical clearance approval in Appendix **F**, meaning:

i) Consent was obtained from participants before any type of participation;
ii) Participants were treated with respect and the right to access the findings was granted;
iii) High confidentiality of the research data has been assured.

CHAPTER TWO: LITERATURE REVIEW

2.1 Planning

2.1.1 Definition

Different authors have characterized the concept of planning as an important function inside an organization.

According to John (2013), planning is the process of setting objectives and figuring out how to achieve them. In other words, Planning entails determining exactly what you want to achieve and the best way to do it. Sarker (2019) said that planning means looking ahead and determining future actions to be taken and is a methodical process that specifies when, how, and by whom a given task will be completed.

Desenzo et al. (2006) argued that Planning is a crucial aspect of human resource management, as it entails determining organizational goals and determining what activities must be performed to accomplish them while Harold Kerzner (2009) explained that planning is the determination of what needs to be done, by whom, and by when to fulfil one’s assigned responsibility.

Putting all the definitions together, planning can be defined as a process of bringing the future into the present and work on it to know more about it in order to reduce uncertainties.

2.1.2 Importance of planning

Planning is the most important function for all organizations because the other functions depend on it (Bwalya, 2020). If it is done well, it establishes a strong foundation for the other management functions. It helps with organizing by allocating and arranging resources to accomplish tasks, leading by guiding the efforts of human resources to ensure high levels of task accomplishment and controlling by monitoring task accomplishments and taking necessary corrective action (Schermerhorn, 2013). In other words, planning helps organizations to achieve their objectives. As argued by Tamanna (2007), Planning is essential not only for obtaining success but also for surviving in today's complex and competitive environment. It forces organizations to look ahead and decide their future course of action improve their profitability.

The planning process has an impact on the company which is doing it, in the way that it affects the performance, facilitates control, and helps the company in the decision-making process (Sarker, 2019).

2.1.3 How planning is done

The planning process of a project or a specific activity is designed based on different criteria which may include: the size and the nature of the organization, the type of planning and so on. Although organizations and types of planning differ, the planning process has a set of fundamental steps to which others can be added. Nine (9) steps have been identified and enumerated below (Project Management Institute, Inc., 2008):

(1) Clear definition of the project objectives;
(2) Establishment of the project scope;
(3) Dividing and subdividing of the project scope into major pieces and work packages (Work Breakdown Structures);
(4) Definition of specific activities that need to be performed for each work package to accomplish the project objectives;
(5) Graphically portraying of activities in the form of network diagram showing sequences and interdependencies;
(6) Making time estimate for each activity;
(7) Estimation of other resources for each activity;
(8) Calculation of the project schedule and budget to determine whether the project can be completed within the required time, with allocated funds and with allocated other resources; and
(9) Adjustment of the project scope, activity time estimates, and resource estimate till a realistic baseline plan is achieved.

2.1.4 Types of planning

According to John (2013), there are four types of planning which are strategic planning, tactical planning, operational planning, and functional planning.

a. *Strategic planning*: Longer-term plans that specify broad action directions and create a frame of reference for allocating resources for maximum performance impact are dealt with in this sort of planning, which is focused on the organization as a whole or a significant component.

The strategic planning is done within different organisations in the following five fundamental steps (Maleka, 2014):

i) Goal setting: Goals, mission statements, values, and organizational objectives are defined in this first step of strategic planning. All these help the organization to continue improving and be competitive in the changing world.

ii) Analysis strategy formation: The organisation's weaknesses and strengths are analysed at this stage. This step considers both internal and external factors such as evolving technology and new competition.

iii) Strategy formation: This step develops specific actions that will enable the organisation to meet its goals.

iv) Strategy implementation: This step puts the strategy into action in order to fulfil the organization's goals. For the successful implantation of a strategic plan, cooperation between management and other personnel is necessary.

v) Strategy monitoring: After the implementation stage, comes the monitoring stage which determines what areas of the plan to measure and the methods of measuring these areas and then compares the anticipated results with the actual ones.

b. *Tactical planning*: Tactical plans are established and used to put strategic plans into action, and they specify how the organization's resources can be employed to accomplish this. Tactical planning can be considered as decision-making on how resources should be allocated to achieve strategic goals (Kataev & Bulysheva, 2014).

c. *Operational planning*: Operational plans define what has to be done in the short term to support strategic and tactical goals. Operational planning is a detailed and executable plan that outlines how a team's tasks and actions contribute to the overarching purpose of the organisation. (Hyun, 2021).

Hyun (2021) proposed five basic steps that can be followed to establish an operational plan:

i) Plot the operational plan: This step gives a high-level overview of the plan's purpose. Having an overview of the purpose is important because it helps to develop the necessary steps to achieve it.

ii) Set goals: After visualizing the plans, goals have to be researched and identified. This step specifies the current condition of the team, where the team should be in a specific period, and the steps that will allow the team to change its state.

iii) Plan the budget: When the goals are known, planners can evaluate the budget needed to cover all the stages leading to the goal achievement.

iv) Create a system for reporting: The reporting system was designed to assist the team in reviewing their plans and keeping track of their progress.

v) Adjust plans when necessary: This step is based on the plan’s flexibility; it refines the plan based on the received feedback.

d. *Functional planning*: Functional plans indicate how different operations within the organization will help advance the overall strategy.

A methodical step by step with nine different steps has been developed for functional planning (Wiles, 2020) :

i) Be strategic-minded: The planners must commit to keeping a strategic mentality from the start of the functional planning process; this is the first stage in functional planning.

ii) Outline expectations: At this stage, to avoid misunderstandings, all participants' expectations, roles, and process timelines must be established and clear.

iii) Verify the business context: Interviewing business leaders is necessary so that they may discuss the existing and future situation of the company.

iv) Assess capabilities: Evaluate the maturity and importance of key functional capabilities required to support overall business goals.

v) Set objectives: A prioritized set of objectives is created at this stage, along with defined and quantifiable stages that describe how each goal will be achieved.

vi) Look to find innovation and growth: Strategic growth objectives should be ambitious by definition.

vii) Put your strategy on a page: This stage summarizes the strategic plan's components on a single page to illustrate how the plan adds value today and how it will affect the future.

viii) Drive the plan home: This must be done by articulating the objectives and strategy across the function and company.

ix) Prepare to respond to change: Once the strategic plan is adopted and shared, it is critical to measure progress against the objectives, revisit and monitor the plan to ensure it remains valid, and adapt the strategy as conditions change.

2.1.5 Limitations of planning

Though planning is a continuous process and can put focus on the companies objectives by affecting its performance (Sarker, 2019), it is limited in the fact that certain factors and events are out of the planner's control such as natural catastrophes and pandemic diseases (such as Coronavirus disease 2019). Six limitations of planning have been defined by Samiksha (2014) as follow:

a. *Planning reduces creativity*: The planning process reduces creativity in the way that, people have to be focused on what is planned, therefore they cannot put in place their ideas, methods, or technical skills.
b. *Planning is a time-consuming process*: Planning is a time-consuming process because it involves the collection of information, analysis, and interpretation, therefore this process takes a lot of time. Thus, planning is limited because it is not suitable during emergencies or crises when quick decisions are required (Juneja, 2015).
c. *Planning does not guarantee success*: Planning is all about setting objectives. There is no guarantee that these objectives will be achieved within the planned time because certain unpredictable events can occur as it is explained above. Therefore, planning is not a guarantee for success.
d. *Planning does not work in a dynamic environment*: The industrial environment is not static, but it keeps on changing. The plans have to be revised for every change to match the environment. Therefore what was planned may not be achieved because of a dynamic environment (Samiksha, 2014).
e. *Planning involves huge costs*: Planning is a costly process in that it involves hiring experts because it is not done by anyone. Samiksha (2014) said also that the planning process needs more time and money to investigate and analyse data.
f. *Planning creates rigidity*: Rigidity appears as negligence to revise the plan, policies, and procedures because inflexibility in an organisation prevents people from doing innovative thinking by being focused on the predefined plans (Saikia, 2015).

2.1.6 Measures to overcome the limitations of planning

Some measures exist to overcome the limitations of planning. Robinson (2005) enumerated some of them as follows:

a. *Manage the change process*: Though planning can reduce uncertainty, there is always a possibility of unexpected events occurring. To overcome this limitation, when planning the planners should make a room for unforeseen situations and be flexible to adapt the plan accordingly.
b. *Communication*: In an organization, a lack of communication about the planning process can cause workers to get confused about the activities that need to be completed, decreasing the planning process' efficacy. To overcome this limitation, effective communication can be applied so that everything is known about where to go, what to do when to do it and who has to do it.
c. *Provide leadership*: The planning process must be supported by the leadership of the organisation. They must lead by example so that all the employees can follow their steps.

2.2 Scheduling

2.2.1 Definition

Scheduling is an important concept that is most of the time attached to planning. Different definitions about scheduling are given below:

Scheduling can be defined as the prescribing of when and where each operation necessary to a certain process is to be performed. In other words, it is the establishing of times at which to begin and complete each event or operation comprising a procedure (Kumar & Suresh, 2008).

Scheduling is defined by Mubarak (2010) as the determination of the timing and sequence of operations in the project and their assembly to give the overall completion time. Simply put, scheduling can be defined as a part of planning which allocates resources and time to the planned activities.

The process of describing in detail which activities must be performed and how the organisation's resources should be utilized to satisfy a given plan is referred to as the scheduling process (Fera et al., 2013).

2.2.2 Type of scheduling

There are different types of scheduling according to the size of the company and the kind of business it is involved in. Below is a shortlist of types of schedules as listed by Bjarmason (2015).

a. *Baseline schedules*: The baseline schedule or schedule baseline is a schedule that is used to measure and monitor the performance of a project. The delivered work at a point in time or over some time is compared against the baseline planned work at the time (Sebastien, 2017).
b. *Detailed schedules*: The detailed schedule is prepared for every activity. It should be integrated into a single master schedule to ensure that all activities are finished on time. (Bjarnason, 2015).
c. *Master production schedule*: The master production schedule is a conversion of production planning into schedule charts and specifics in terms of specified end items or models to which priorities can be assigned (Kiran, 2019).
d. *Look ahead schedule*: The look-ahead schedule is a schedule that communicates the planned work for the next few days, weeks, or months (Epperson, 2020).
e. *Weekly work schedule*: This schedule presents the activities planned over one week to give an overview (Bjarnason, 2015).

2.2.3 How scheduling is done

The scheduling process is also designed based on the organisation's size and nature as explained previously for the planning process. However a standard process with six steps has been proposed (Roseke, 2017) :

i) Planning of schedule management

   This step is the process of establishing the policies, procedures, and documentation for planning, developing, managing, executing, and controlling the project schedule. This process provides guidance and direction on how the project schedule will be managed throughout the project (Roseke, 2017).

ii) Definition of activities

   Defining activities is the process of identifying the specific actions to be performed to produce the project deliverables (Project Management Institute, Inc., 2008).

iii) Sequence of activities

   This is the process of identifying and documenting relationships among the project activities. The benefit of this step is that it defines the logical sequence of work to obtain the greatest efficiency given all project constraints (Project Management Institute, Inc., 2008).

This process is important because it controls task sequencing and task start and end dates. There are four types of task relationships (Kenelly & Croswell, 2020):

- Finish-to-Start relationship: An activity must finish before another starts
- Start-to-Start relationship: An activity cannot start until another activity starts
- Finish-to-finish relationship: An activity cannot finish before another activity finishes
- Start-to-finish relationship: An activity must start before another can finish.

iv) Estimation of activity resources

This stage entails calculating the types and amounts of materials, personnel, equipment, and supplies needed to complete each task. (Project Management Institute, Inc., 2008).

v) Estimation of activity durations

This is the process of estimating the length of time it will take to execute various tasks using estimated resources. (Project Management Institute, Inc., 2008).

vi) Development of schedule

The development of schedules is the last step in the scheduling process, it is a process of analysing activity sequences, durations, resource requirements, and schedule constraints to create the project schedule (Project Management Institute, Inc., 2008).

2.2.4 Scheduling problems

There are some problems when it comes to scheduling activities for whatever technique is used or type of schedule. Harold Kerzner (2013) has identified some of the relevant problems which include:

- *Using unrealistic estimates for effort and duration:* The whole process of scheduling is based on estimations. If the estimations are not realistic, they will affect the schedule. Thus, the scheduler must overestimate or add some schedule reserve at the end of the schedule to cover unforeseen circumstances (Frederick & Plummer, 2007).
- *Continuous readjustments to the work breakdown structure (WBS)*: The WBS is important in the scheduling process because it divides the job into small tasks. The WBS tasks have clearly defined limits thus, the scheduler can determine how advanced the job is by checking which of the tasks are finished (Markgraf, 2019).

  As the schedule is based on the WBS, any readjustment on it means schedule readjustment, therefore this stands as a problem or limitation to the scheduling process.

- *Unforeseen bottlenecks*: A bottleneck is any resource whose capacity is less than the demand placed on it. Reid & Sanders (2012), said that there are common bottlenecks in the scheduling processes which result when one operation in a job takes longer than the other operations (document approval, availability of resources, interlinked services…)

2.3 Planning and scheduling in the mining industry

The planning and scheduling process in Electrical engineering falls under the maintenance department as far as the mining industry is concerned. This section presents an overview of the maintenance concept and shows how the planning and scheduling process is done in mining companies.

2.3.1 Definition of maintenance

Maintenance is the act of maintaining which includes keeping, preserving and protecting (Smith & Keith, 2007). Maintenance is defined as the actions taken to keep the condition and performance of a machine in the same state as when it was first purchased (Sivaranjith, 2019). Maintenance is the process of keeping equipment in a functional state, either by preventing it from failing or by restoring it to a functional state once it has failed (Krishna, 2008).

2.3.2 Type of Maintenance

There is a specific type of maintenance required for each piece of equipment; some need periodic checking, others just need alignment, yet others require lubrication and so on. As explained by Kumar & Suresh (2008), different approaches have been developed to know how maintenance can be performed to ensure equipment reaches or exceeds its design life. These approaches include reactive maintenance (RM), PM, PdM, and reliability centred maintenance (RCM).

a. Reactive maintenance (RM)

Also called breakdown maintenance or corrective maintenance, the RM is a ‘run to failure’ maintenance and it is the oldest maintenance type. In this type of maintenance, actions are taken after the occurrence of the failure. RM consists of the actions taken to restore a failed equipment or system to an operational state (Krishna, 2008).

In maintenance strategies, concepts and approaches written by Gackowiec (2019), the RM is pointed out as the simplest type of maintenance though expensive because it is used as a reaction to breakdowns and all consequences of such incidents. As stated by Kumar & Suresh (2008), RM has two advantages, it involves low-cost investment for maintenance and requires less staff. Compared to advantages, RM has many disadvantages. It increases the cost due to unplanned downtime of equipment, the labour cost (especially if overtime is needed), it involves repair or replacement costs of equipment, it uses the staff resources inefficiently and has a possibility of secondary equipment or process damage from equipment failure. Other concerns with RM are unexpected loss of production, possible safety risk and loss of containment (John & Joseph, 2016).

b. Preventive maintenance (PM)

PM is defined as actions performed on a time or machine-run-based schedule that detect, preclude, or mitigate degradation of a component or system with the aim of sustaining or extending its useful life through controlling degradation to an acceptable level (Kumar & Suresh, 2008). In opposition to the RM, PM aims to prevent equipment failure. Therefore, it is carried out on equipment that is not in failure yet (Trojan & Marcal, 2017). Usually, it is performed on a regular basis based on the expected life of the equipment and the frequency of the maintenance is generally constant (Krishna, 2008). This type of maintenance is referred to as time-based maintenance or planned maintenance. As stated by Gackowiec (2019), it is a response to the disadvantages of corrective actions. Equipment life is extended and dependability is increased simply by allocating the appropriate resources to carry out the maintenance tasks specified by the equipment designer (Kumar & Suresh, 2008). There are some advantages and disadvantages of PM. The advantages include the reduction of equipment or process failure, increased component life cycle, flexibility in maintenance periodicity and the disadvantages include labour intensive, performance of unneeded maintenance, the possibility of catastrophic failure occurrence (Kumar & Suresh, 2008).

c. Predictive maintenance (PdM)

This type of maintenance is also carried out before the occurrence of the failure. It has been defined by Kumar & Suresh (2008) as measurements that detect the onset of a degradation mechanism thereby allowing causal stressors to be eliminated or controlled prior to any significant deterioration in the component physical state. The goal of this sort of maintenance is to keep an eye on the system and its components, as well as to analyse the condition of products and anticipate the risk of damage based on the information acquired (Gackowiec, 2019). The PdM can be said to predict equipment failure and then to help to decide when to make the intervention to repair this equipment. It is scheduled corrective maintenance or a condition-based PM (Trojan & Marcal, 2017). The PdM reduces time spent on maintenance and machine breakdowns or unexpected failures, decreasing unplanned downtime and expenditures spent on labour, spare parts, and equipment. The disadvantages of PdM are that it is a detailed and time-consuming approach, it requires skilled staff and condition-monitoring equipment (Maiti, 2021).

Krishna (2008) stated that this type of maintenance is typically performed on mechanical systems with historical data available for evaluating system performance and maintenance models, as well as known failure modes.

d. Reliability centred maintenance (RCM)

RCM is a process used to identify the most applicable and effective maintenance actions to ensure the highest practical standard of the operating performance of a system or a component (Salih & Raouf, 2015). It acknowledges that not all equipment in a facility is equally important to process or facility safety, equipment design and operation differ and that different equipment will be more likely to fail due to distinct degradation mechanisms than others (Kumar & Suresh, 2008). RCM has 3 objectives as stated by Salih & Raouf (2015), to establish the most cost-effective and suitable maintenance chores in order to reduce the risk of failure and its influence on equipment operation, to ensure high safety and reliability performance, and to maintain system and equipment functionality in the most cost-effective manner. These objectives are defined by the functions and performance standards required for any item in their operating environment and its application is an ongoing process and should be evaluated frequently (Trojan & Marcal, 2017).

According to Kumar & Suresh (2008), savings potential not readily seen by management and significant cost, training, equipment, etc., are the major disadvantages of RCM. The advantages are that it minimizes the frequency of overhauls, reduces the probability of sudden equipment failure, increases components reliability, incorporates the root cause analysis, has the ability to focus maintenance on critical components, and is the most efficient maintenance program.

In addition to these approaches, modern approaches are being used nowadays which include lean maintenance and six sigma maintenance. Six sigma maintenance is the application of six sigma principles in maintenance while the application of the lean principle in a maintenance environment is called lean maintenance.

2.3.3 Planning and scheduling process

As explained in Chapter **1**, section **1.1** the planning and scheduling process is very important for a mining company. This section describes the planning and scheduling process in production-based companies in general and mining companies in particular.

Kumar & Suresh (2008) mentioned six main steps to be followed for proper planning within a production based company such as a mining company. These steps include the knowledge base, the job investigation at the site, the identification and documentation of the work, the development of repair plan, the preparation of tools and facilities list as well as the estimation of time required to do the job.

1. **Knowledge base**: This is the first step in the planning process, it involves the knowledge of equipment, job, techniques to be used, materials and facilities
2. **Job investigation at the site**: This step gives a clear perception of the total jobs. It includes a visit to the place where the job will be done to
3. **Identification and documentation of the work**: The aim of this step is the knowledge of the two earlier steps and the needs of PM, PdM or other maintenance jobs
4. **Development of repair plan**: This is a preparation of step by step procedures that would accomplish the work with the most economical use of time, manpower and material.
5. **Preparation tools and facilities list**: Indicating the need for special tools, tackles, and facilities needed.
6. **Estimation of time required to do the job**: Done with work measurement techniques and critical path analysis.

For effective planning in the mining industry, Frieser (2020) stated six steps as well which include the equipment identification work, having a support network, defining an effective program, using information efficiently, establishing organization levels and finally evaluating and performing measurements.

1. **Equipment identification work**: For the planning process to start, the work to be done must be identified for the concerned equipment.
2. **Have a support network**: This step considers that the maintenance in mining companies is not carried out in isolation, it requires a series of interlocking operations.

3. **Define an effective program**: This step sets the procedures for requesting, assigning, monitoring, measuring, and evaluating maintenance activities. The objective is to be sure that the plan will be carried out as stipulated
4. **Use information efficiently**: The data collected for past works will be used at this stage for future similar works.
5. **Establish organisation levels**: It is possible that many professionals are involved in different stages of the process planned. Therefore, this step establishes the relationship between different participants to the job in order to facilitate the process control.
6. **Evaluate and perform measurements**: This step comes after the execution of the work in order to verify if it was done following the required standard

Christian (2017) explained that for Tenke Fungurume Mining, which is one of the great mining companies in the Democratic Republic of Congo, the planning section of the maintenance department is responsible for all the works done. The planning section must plan and examine everything before beginning any work. With this approach, the electrical and mechanical sections are just executors. Five steps were identified in the planning and scheduling procedure of Tenke Fungurume Mining (Christian, 2017):

1. **Understanding of the job**: The planners study the job to be performed and its contribution to the company's productivity.
2. **Area of work**: This step is all about the place or environment where the job will be performed to identify all the constraints with regard to tools, equipment and safety.
3. **Proposition of Techniques:** At this step, the planners propose a procedure of the job execution, from the safety permit to the very end of the job.
4. **Time and Resources**: The planners gather previous similar jobs to assess the time and resources needed for a given job.
5. **Safety and permission**: The planning section provides all the instructions concerning the safety constraint linked to the job. Because if safety is number one in any other company, it is number zero for Tenke Fungurume Mining (Christian, 2017).

2.4 Planning and scheduling at AMC

The planning and scheduling process referred to in this research concerns the Electrical Engineering Section in particular and the maintenance department in general. This part of the dissertation presents an overview of the maintenance department and explains how the planning and scheduling process is done at AMC for both the Planning and Electrical sections.

2.4.1 Maintenance department

The company AMC has many departments such as human resources, logistics, project, mining, security and maintenance. The maintenance department is one of the important departments because its role is to ensure all the time a good working condition of machines to allow an effective production. This department has 3 sections: Electrical engineering, Mechanical engineering, and planning section. It is organised as shown in Figure **2.1**. However as stated in chapter one, this research looked only at the electrical engineering and planning section.

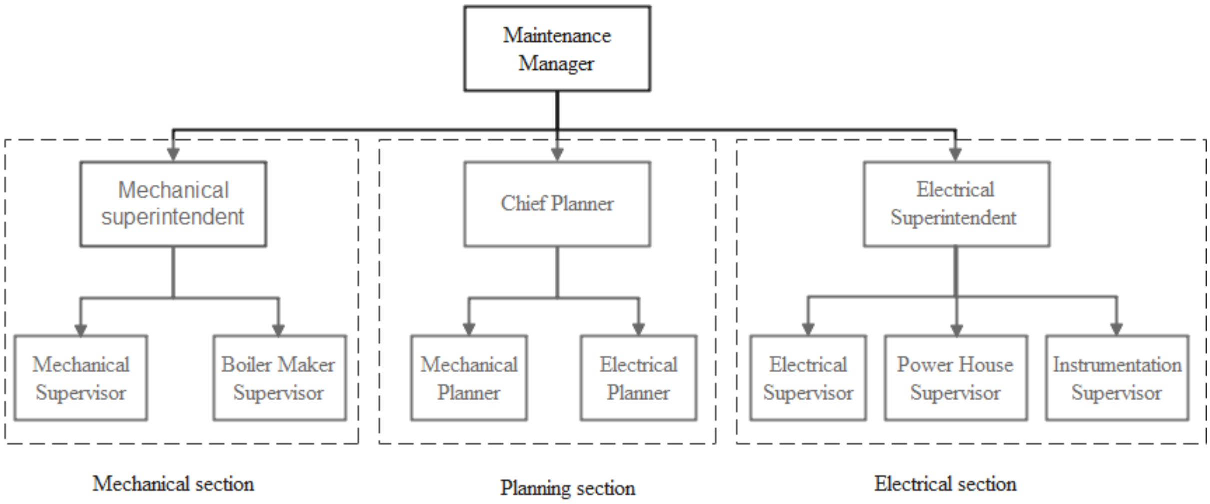

Figure 2. 1. Organisation chart of the department of maintenance

The mechanical superintendent reports to the maintenance manager and he is the one to whom the mechanical supervisor and boilermaker supervisor report. The electrical, powerhouse and instrumentation supervisors report directly to the electrical superintendent who reports to the maintenance manager for the Electrical Engineering Section.

In the planning section, the mechanical and electrical planners report to the maintenance manager via the chief planner. It should be noted that since the reopening of the company in 2018, the position of the chief planner is vacant and the planners both mechanical and electrical report directly to the maintenance manager.

2.4.2 Planning section

The role of the planning section is to plan and schedule all the activities with respect to maintenance, from the stock management to the work plans and schedules. This section regroups 3 persons; 2 planners, one for the Electrical Section and one for the mechanical section, and one data clerk. For maintenance management, the company uses PRONTO XI as the computerised maintenance management system.

The planning section gathers daily equipment information according to their functions, to generate the PM activities monthly. The information gathered include current and temperature for motors and ball mills, running hours, oil and fuel consumption for the generators, temperature for transformers, etc. Appendix **D** shows some examples of the PM work orders delivered. Designed checklists are used to collect these data based on the parameters to measure for each piece of equipment. Appendix **E** shows some examples of the checklists used in the Electrical section.

At the end of a month, based on the data collected, the planning section uses the maintenance management system to forecast all the PM activities for the next month. The maintenance tasks to be performed and the time between two PM are provided by the manufacturer for each piece of equipment. Therefore, there are daily, weekly, monthly, two monthly and quarterly services to be carried out for different equipment.

In addition to these tasks, planned and scheduled shutdowns are also among the tasks of the planning section. To ensure the production is not stopped, shutdowns are done per unit and on different days. The plant has 3 major units: Crushing, Milling, and Flotation. At least one shutdown is scheduled per month to keep the plant productive.

The planning and scheduling process of shutdowns is done in the meeting called by the maintenance manager with the planners, the superintendents as well as all the supervisors. The tasks to be carried out are listed and the estimated time for completion is discussed in this meeting before any implementation in Microsoft Project which is the software used for the shutdown planning. After the meeting, the planning section prints out a shutdown sheet to be distributed to any workers who will have a task to perform during the shutdown.

For the other activities of the maintenance department, the planning section is supposed to plan them before the execution to facilitate the work. Meaning when a job request is released by a given section in need of the maintenance department, it is supposed to go first to the planning section which will plan and schedule the job using PRONTO XI and the job will be saved with a ‘planned’ status. After this step, the planning section goes to either the mechanical or Electrical Section to give the job request and allow the commencement. Once the job starts, the planning section changes the status of the job into ‘in progress’ until the job is completed for it to change into ‘completed’ status.

However, unfortunately, the job request just comes to the planning section from the electrical or mechanical section after the job is complete or in other cases, it doesn’t even come back.

This makes it hard for the job of the planning section in the way that it is difficult to evaluate the performance of the sections in particular and the department in general.

2.4.3 Electrical Engineering Section

At the Electrical Engineering Section, every day after the morning safety meeting, an electrical situation of the plant is presented by the night shift team. Then based on the job requests received and the situation of the plant, the activities to do during the day are just listed by the supervisors.

Listing the activities to do during the day is not enough for the section to perform them efficiently because there are not planned. Though the activity is listed, the section finds itself, sometimes unprepared with regard to tools because there was no prior planning of the activity or with respect to human resource availability because the shifts of workers do not provide a constant number of workers in the section every week.

In other words, the planning and scheduling process of the Electrical Section ends with the list of activities to be done per day which includes neither availability of human resources nor the preparation of tools or time estimation for the activities.

The following table compares different steps in the planning and scheduling process in the mining industry with AMC.

Table 2. 1 Comparison of the planning and scheduling approaches used in the mining industry

	Production-based company (Kumar & Suresh, 2008)	Tenke Fungurume Mining (Christian, 2017)	Mining industries (Frieser, 2020)	Anvil Mining Congo SA	
				PM activities	**Daily activities**
1	Knowledge base	Understanding of the job	Equipment identification	Area identification	Equipment identification
2	Job investigation at the site	Area of work	Have a support work	Equipment identification	Execution
3	Identification and documentation of the work	Proposition of techniques	Define an effective program	Generation of the PM task	
4	Development of repair plan	Estimation of time and resources	Use past information efficiently	Techniques proposition	
5	Tools and facilities list	Safety and permission	Establish organisation levels	Safety considerations	
6	Estimation of time required	Execution	Execution	Execution	
7	Execution		Evaluate and perform measurements		

Table **2.1** shows that for the planning and scheduling approach used in a production-based company suggested by Kumar & Suresh (2008), six steps are important before the execution of the activity. For Tenke Fungurume Mining, before the execution of an activity, five steps are required (Christian, 2017). Frieser (2020) has listed five steps before the execution of an activity and one after the execution in mining industries.

For AMC, concerning the PM activities which are planned by the planning section, the planning and scheduling process involves five steps before the execution of the activities. But for the Electrical Engineering section, Table **2.1** shows that only the identification of the equipment is required before the execution of the activity. Therefore, activities are executed without any prior planning and require more time and more human resources because of the lack of proper planning and scheduling.

2.5 Maintenance Backlog

The electrical section's consistently high percentage of PM backlog indicates poor backlog management. This section provides a summary of the maintenance backlog, as well as strategies to reduce the proportion of the backlog.

2.5.1 Definition

The maintenance backlog is an incredibly important part of the maintenance process that deals with all the maintenance work that has been approved but has not yet been completed (Prometheus Group, 2020). Defining backlogs in maintenance, Finch (2021) said that there are two perspectives: the first perspective is that it is a set of planned work that has yet to be scheduled, while the second is that it is a series of works that have yet to be completed by the due date. To provide a clear explanation of maintenance backlog and to connect the two perspectives, Cousineau (2020) stated that maintenance backlog is not work that is simply past its due date, but all maintenance work that is being planned, approved, and scheduled, but not completed.

2.5.2 Measurement and reduction process

Depending on a company's maintenance philosophy, maintenance backlogs are measured in a variety of ways. As explained by McGroarty (2013), to calculate the maintenance backlog, the workload or week of work is employed as a unit, while Gehloff (2015) measures it in terms of weeks of backlog and Rumburg (2021) measures it in percentage.

There are various methods to reduce maintenance backlogs, regardless of the units. A five steps process was proposed by MPulse Software, Inc. (2018):

i. **Identify what needs to be done**: This first step identifies and organizes the work to be done by asset, task type, location, or available resources.
ii. **Prioritize**: The selected work to be done has to be listed by priority, considering the emergency, criticality, or safety aspect.
iii. **Determine what resources are needed**: At this stage, the labour time has to be estimated for each task and every necessary part or inventory.
iv. **Revise the plan**: This step is all about assessing the progress of the work to see if the process of reducing backlogs is going well. This step also adjusts the initial plan to meet the actual requirements.
v. **Act on the discoveries**: During the reduction of backlog, new aspects can be discovered and worked on to improve the maintenance approach.

Along the same line of backlog reduction, Cousineau (2020) suggested a process of six steps:

i. **Get buy-in**: The first stage is to change the minds of workers by showing them, through data, how the maintenance backlog reduction will benefit them.

ii. **Prioritize the work**: The first thing before starting work is to rank the tasks by priority. Prioritization relies on maintenance goals, but there is one technique to pick which work to complete first: Determine the length and difficulty of the remaining work orders based on the assessed criticality, filter work on critical assets based on how late it is, and prioritize based on the assessed criticality.

iii. **Assess the resources**: This step is all about assessing the resources available to the team to do the job.

iv. **Plan for risks**: Major rebuilds, time-consuming and difficult projects, and work that the team hasn't done in a long or before are all examples of high-risk jobs that can be found in a backlog. These risks have to be mitigated and reduced by giving technicians additional training, adding more technicians and work hours, and making sure the right personal protection equipment (PPE) is available.

v. **Build work orders for efficiency and safety**: This process generates excellent work orders to assist professionals in safely, efficiently, and properly completing backlogged maintenance tasks. Some key areas of a work order make this possible: Clear and detailed task lists to eliminate confusion and wasted time; a list of required PPE; manuals, diagrams and pictures; an in-depth description of the problem and completion notes.

vi. **Keep track of everything**: This last step measures progress once the plan is in motion to allow the adjustment of strategies.

2.6 Literature review summary

This chapter has gathered sufficient information regarding the various ideas included in this study, such as planning, scheduling, and maintenance backlogs.

Concerning the planning and scheduling concepts, the literature presented four types of planning that include strategic planning, operational planning, tactical planning and functional planning; and five types of schedules which are baseline schedules, detailed schedules, master production schedule, look ahead schedule and weekly work schedules. Based on activities in the electrical engineering section of AMC, this study used operational planning and detailed schedules.

The literature presented four types of maintenance that include reactive maintenance, preventive maintenance, predictive maintenance and reliability centered maintenance. For the activities performed at AMC, this study considered only reactive and preventive maintenance.

The AMC Planning and Electrical Engineering sections were presented and the Planning and Scheduling process was discussed and compared with different processes used in the mining industry. The maintenance backlog management was also discussed in this chapter and two reduction processes were presented to overcome the backlog issue that influences the efficiency of the electrical engineering section the same way that failure of planning does as well.

CHAPTER THREE: METHODOLOGY

3.1 Research design

This research started with a review of the literature on planning and scheduling. The company on which the investigation of the effects of planning and scheduling was done is ANVIL MINING CONGO SA. The research used a quantitative approach and experimental design to achieve its objectives. From the literature review to the conclusion and recommendations, this research passed through different steps as shown in Figure **3.1.**

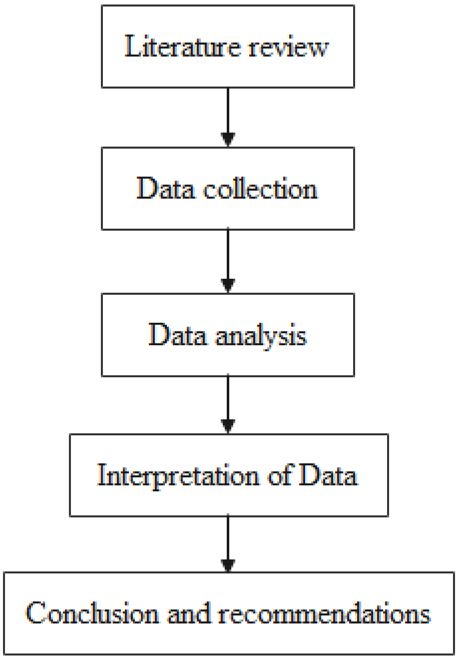

Figure 3. 1. Research Design

3.2 Instruments used in data collection

Using the quantitative approach, this study was based on the experimental design strategy which is a concept used to organize, conduct and interpret results of experiments in an efficient way, making sure that as much useful information as possible is obtained by performing a small number of trials (Djuris et al., 2013). This research used observation and desk study as instruments for data collection. Observation is a data collecting tool that entails looking at things like objects, resources, processes, relationships, and events and formally capturing the data (Simister, 2017). However, A desk study, also known as a document review, is a secondary data collection approach that gathers information by using existing data (Lalehzari, 2021).

As explained in the data collection procedure (section **3.3**), the observation was used to record the time spent and the resources needed for each planned activity, while the document review was used to gather the records of the Electrical Section (unplanned activities) that served as a basis to compare the performance of the section.

3.3 Data collection procedure

With the data collection instruments identified in section **3.2**, the procedure used to collect data in this research is as represented in Figure **3.2**.

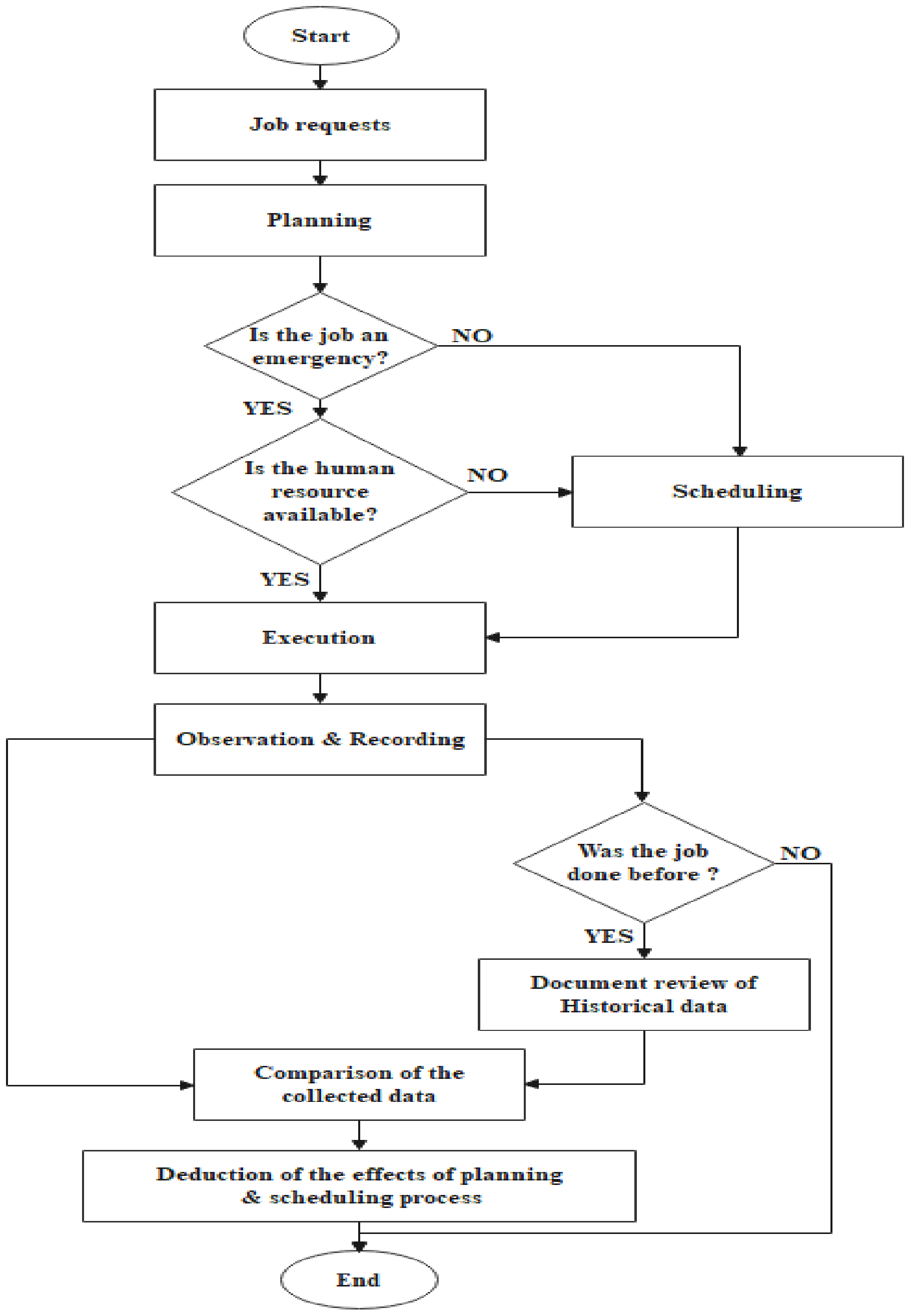

Figure 3. 2. Data Collection procedure

The data collection procedure started with the job requests received in the section per day. For a given job request, the first step was to apply the planning and scheduling process.

Based on the emergency and the availability of human resources, the activity was planned to be carried out or scheduled for a suitable day. After the execution of the activity, the time spent and the human resources allocated to the activity were recorded.

If the job has never been done, the process ends with a record of the time spent and the human resources allocated for future use. In case the job has been done before, through a document review of the historical data, the recorded data (time spent and resources allocated) was collected. Having two collected data sets, respectively, from the historical data (without any prior planning and scheduling) and from the records after execution following the planning and scheduling process, the next step was the comparison of these data sets to deduct the difference and highlight the effects of the planning and scheduling process.

The data collection procedure was based on the theories stated by Harold (2013) about planning and scheduling saying that planning improves efficiency and scheduling is well done if realistic estimates are applied. The duration of activities was studied because proper planning reduces the risk of time overruns and enhances outcome quality and operational safety (Umar et al., 2019).

For the experimental design approach, planning and scheduling were considered as independent variables and determined the performance of the section, which are the dependent variables, as shown in Figure **3.3**. It was assumed that the only independent variables were planning and scheduling without considering the environment that might also have an influence on the dependent variables.

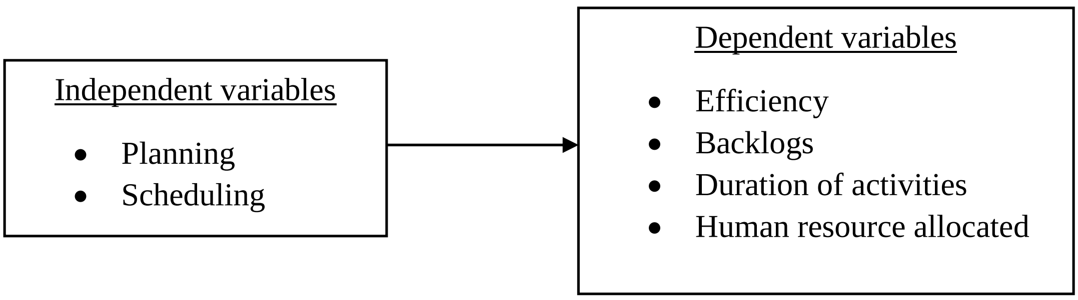

Figure 3. 3. Dependence of the performances on the planning and scheduling process

3.4 Data analysis instrument

The data collected were analysed using Microsoft Excel, especially its statistical data analysis aspect.

3.5 Proposed planning and scheduling process

The planning and scheduling process suggested to the Electrical Engineering Section during the data collection period was the one proposed by Kumar & Suresh (2008) concerning production-based companies with an aspect of scheduling and safety. The following are the steps of the process.

1. Knowledge base
2. Job investigation at the site
3. Emergency assessment
4. Identification and documentation of the work
5. Resources availability assessment
6. Development of repair plan
7. Tool and facilities list
8. Estimation of time required
9. Safety considerations

CHAPTER FOUR: DATA COLLECTION AND ANALYSIS

This chapter is dedicated to the analysis of the data collected during the research period. The analysis process gathers all the data and presents them in an easy-to-understand form to facilitate interpretation.

The collected data include the PM backlogs and the monthly efficiencies of the electrical section from January 2019 to December 2021, the duration of some activities and the human resources allocated to them, from May to December 2021 as explained in chapter **3**.

4.1 Efficiency of the section

Every day, based on the job requests and the projects of the section itself, the Electrical engineering section has a certain amount of jobs or activities to be done. However, at the end of the day, only some of the activities are done. This leads to the notion of efficiency.

The efficiency of the section as shown by Equation **4.1**, is computed as a ratio of the activities done over the activities that were supposed to be done; therefore, the efficiency will only be between 0 and 1.

$$\eta = n/N \qquad \textbf{(4.1)}$$

Where,

η: efficiency of the section
n: number of activities done
N: number of activities to be done

The monthly efficiencies of the Electrical engineering section were computed for the years 2019, 2020, and 2021 to compare the figures within the period with and without the planning and scheduling process. Appendix **B** shows in detail the number of weekly activities done and to be done for all the months.

For the year 2019, the different monthly efficiencies of the electrical section have been collected and are gathered in Table **4.1**. To facilitate the understanding and show the trends, these efficiencies are represented in a chart form in Figure **4.1**.

The trends on the chart reveal that for the year 2019, the maximum efficiency of the section was 83% and occurred in April while the minimum was 69% and occurred in October; this low efficiency was due to the fact that two workers resigned between September and October 2019. Therefore, the company had a shortage of manpower in the Electrical section. Though 83%

was the maximum of the year, it was under the world maintenance standard which requires the efficiency to do be less than 90% as mentioned in chapter 1.

Table 4. 1 Efficiencies of the section for the year 2019

	Activities done (n)	Activities to be done (N)	Efficiency (η) (%)
January	49	61	80
February	48	59	81
March	45	58	78
April	59	71	83
May	51	69	74
June	53	70	76
July	40	51	78
August	39	53	74
September	47	65	72
October	37	54	69
November	49	60	82
December	49	67	73

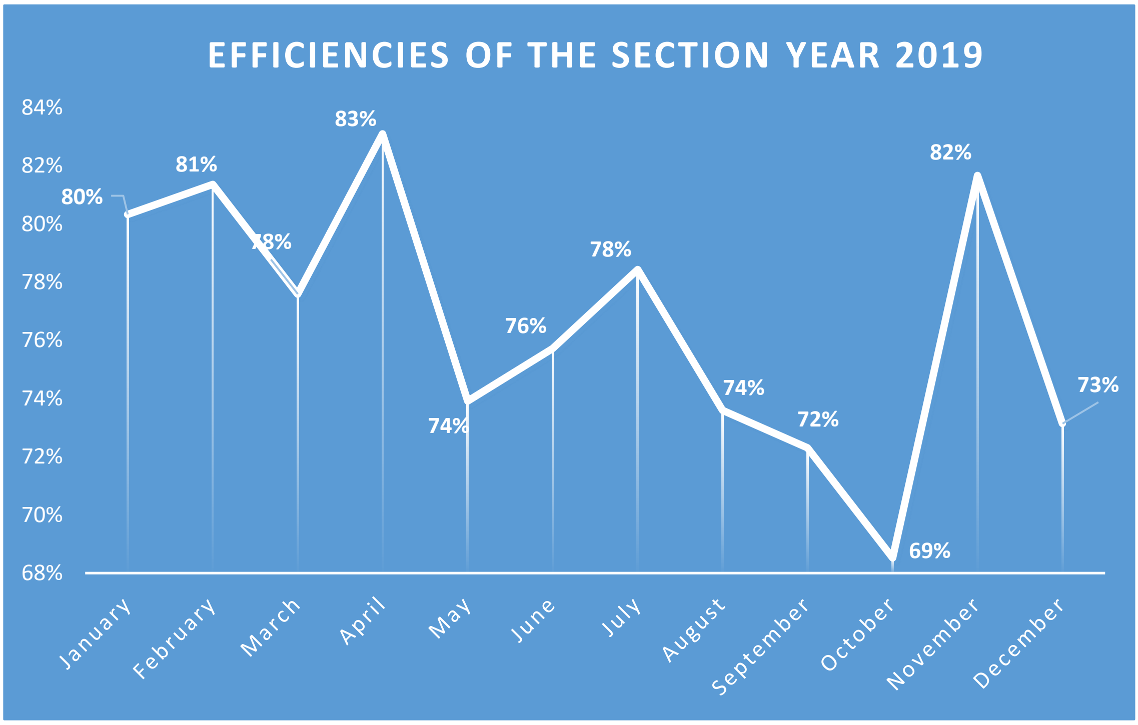

Figure 4.1. Monthly efficiencies of the electrical section for the year 2019

For the year 2020, the monthly efficiencies were collected and are shown in Table **4.2**. The trends are represented in Figure **4.2** which reveals that the maximum efficiency was 83% as in 2019 and occurred in December, and the lowest efficiency was 71% and occurred in May. Again, the planning and scheduling system was not as good as the world standard requires it to be the reason why the efficiency was less than 90%.

Table 4. 2. Efficiencies of the section for the year 2020

	Activities done (n)	Activities to be done (N)	Efficiency (η) (%)
January	37	50	74
February	50	61	82
March	51	63	81
April	49	60	82
May	40	56	71
June	48	59	81
July	47	57	82
August	59	72	82
September	60	81	74
October	57	77	74
November	61	79	77
December	59	71	83

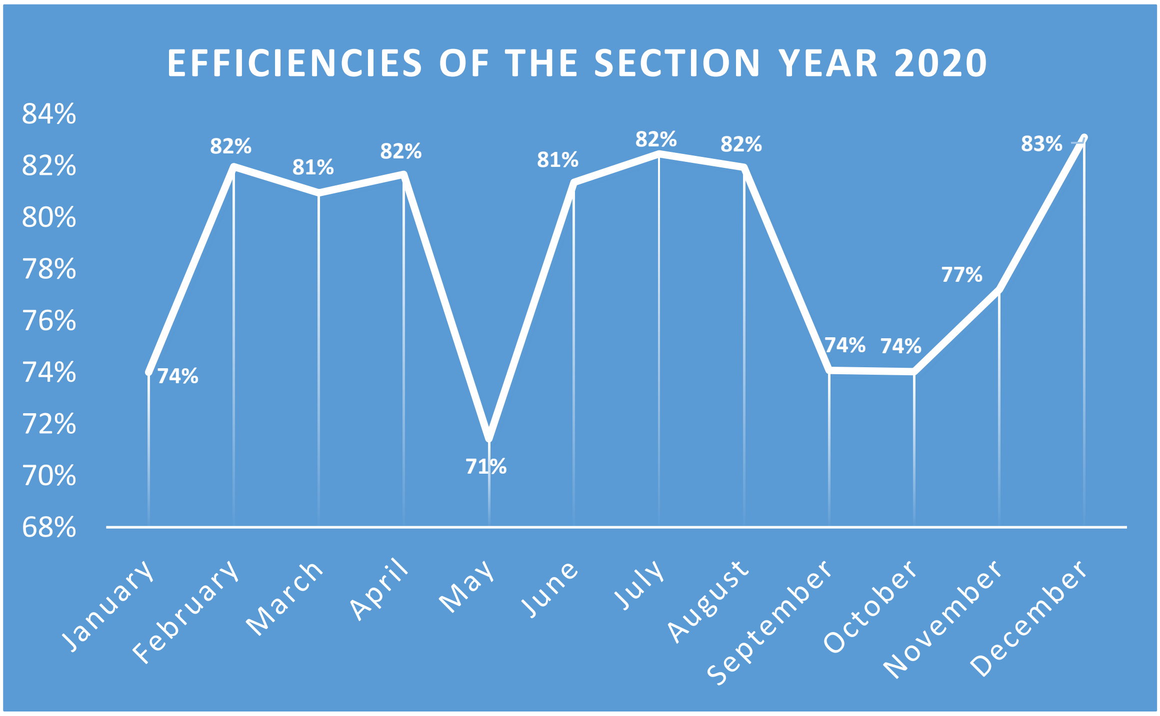

Figure 4. 2. Monthly efficiencies of the electrical section for the year 2020

For the year 2021, during which the daily planning and scheduling process has been introduced, the efficiencies of different months were collected and are shown in Table **4.3**. The trends are represented in Figure **4.3**.

Table 4. 3. Efficiencies of the section for the year 2021

	Activities done (n)	Activities to be done (N)	Efficiency (η) (%)
January	47	56	84
February	75	89	84
March	46	57	81
April	69	83	83
May	58	63	92
June	64	67	96
July	74	79	94
August	78	82	95
September	29	37	78
October	64	67	96
November	61	65	94
December	65	68	96

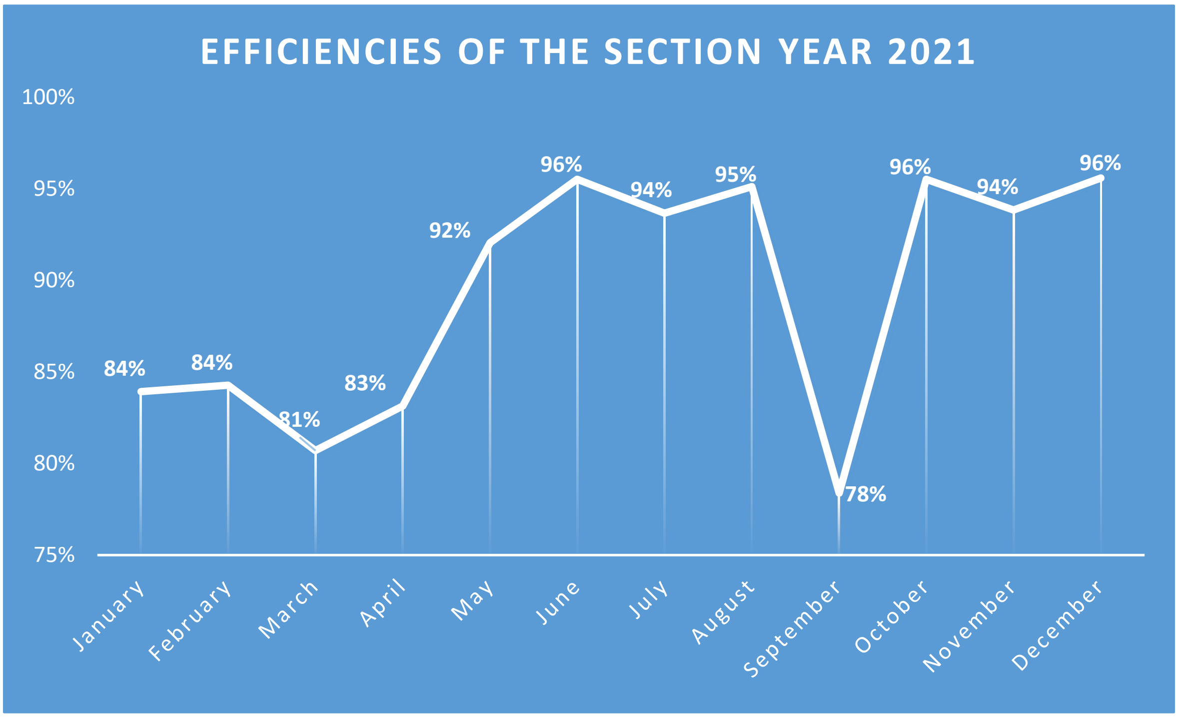

Figure 4. 3. Monthly efficiencies of the electrical section for the year 2021

The chart of 2021 shows an augmentation of the efficiency since the month of May. For the first time since 2019, the efficiency of the Electrical section reached 92%. This augmentation of the efficiency is due to the implementation of the planning and scheduling process which began in May 2021 because that is the only parameter that changed and as discussed in section **3.3**, the theory of Harold (2013) says that planning improves the efficiency has been verified.

Furthermore, Figure **4.3** shows that in the month of September, the Electrical section recorded the lowest efficiency of the year (78%). This reduction of efficiency was due to the fact that the company stopped production from the 1st to 13th September, and was negotiating with the government concerning some taxes over mining companies. Therefore, many activities were planned but only some of them were executed since the human resources were reduced and the production chain was down. The section only remained with a restricted number of workers to ensure the minimum service of the plant.

On the 13th September 2021, the company resumed production and the section took over from there to carry out some of the activities that were planned but were not executed yet because of the shutdown. As expected, the efficiency of the section was low for the month of September because there were a lot of job requests which were not executed during the break time.

4.2 PM Compliance

The planning section which is under the maintenance department as explained in chapter two uses a PM approach for different equipment. Therefore, PM activities are generated monthly and distributed to both electrical and mechanical engineering sections to be carried out.

Added on top of other activities they have, the sections may not complete all the PM activities provided by the planning section. Therefore, there is a notion of backlog that expresses the percentage of the PM activities planned but not executed at the time they were supposed to be executed. The PM compliance report is compiled monthly by the planning section. The percentage of the backlog is computed using equation **4.2**.

$$B = 1 - \left({}^{R}/_{I} \right) \qquad \textbf{(4.2)}$$

Where,

B: Backlog
R: PM Activities executed
I: PM activities issued

This study analysed for the Electrical engineering section the monthly PM compliance reports from January 2019 to December 2021. The following table represents the monthly backlogs of the Electrical engineering section of the year 2019.

Table 4. 4. Monthly backlogs of the Electrical section for the year 2019

Electrical PM compliance 2019			
Month	Issued	Received	**Backlog (%)**
January	248	107	57
February	135	57	58
March	44	23	48
April	104	78	25
May	192	140	27
June	192	98	49
July	135	0	100
August	112	0	100
September	181	16	91
October	386	356	8
November	438	306	30
December	429	309	28

To make visible the trends and facilitate the understanding of the figures, these backlogs are represented in a bar chart form in Figure **4.4**.

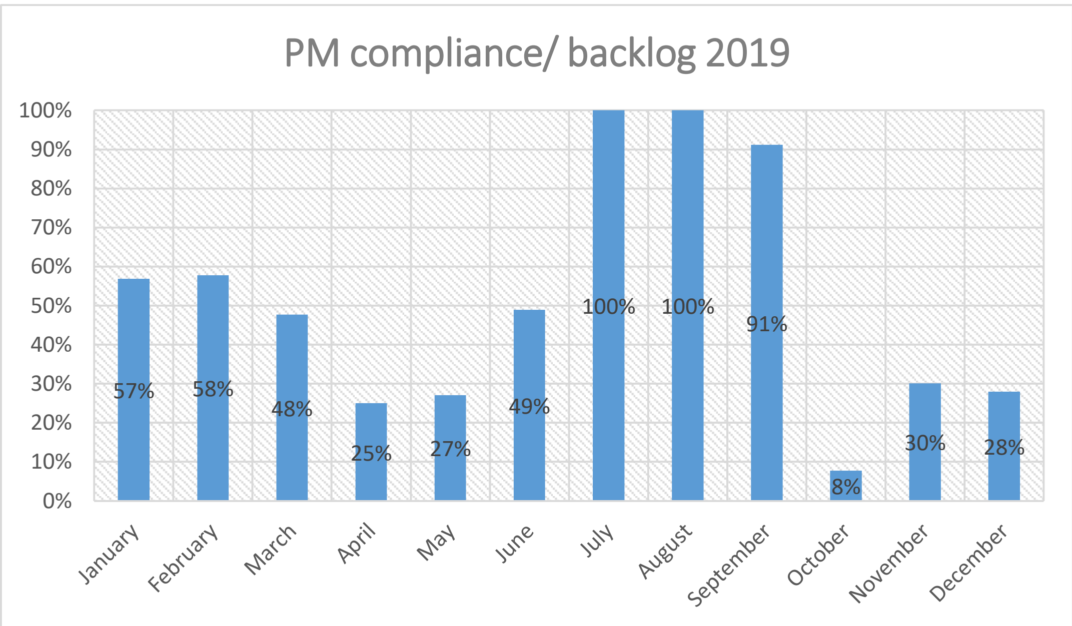

Figure 4. 4. PM Compliance report of the Electrical section for the year 2019

For July and August 2019, the compliance reports show 100% as a percentage of backlogs. This happened because the section was working on a project of adding a new section (reagent section) in the plant and during this same period, more than two shutdowns were supposed to be done. Therefore, the section did not have enough time for the PM activities.

For the year 2020, the different backlogs of the Electrical section have been collected from the PM compliance reports and are shown in Table **4.5**.

Table 4. 5. Monthly backlogs of the Electrical section for the year 2020

Electrical PM compliance 2020			
Month	Issued	Received	**Backlog (%)**
January	345	158	54
February	270	21	92
March	335	5	99
April	244	139	43
May	373	63	83
June	352	14	96
July	329	207	37
August	383	261	32
September	380	276	27
October	293	199	32
November	284	282	1
December	419	395	6

Table **4.5** shows that in November and December 2020, the section performed very well in terms of backlogs. Planners' explanations for these exceptionally high compliance levels were that there were low workloads during the period covering those months. This performance is visible in Figure **4.5** which presents the backlogs in a bar chart form.

For the year 2021, during which the daily planning and scheduling process was introduced, the backlogs of different months were collected and are shown in Table **4.6**.

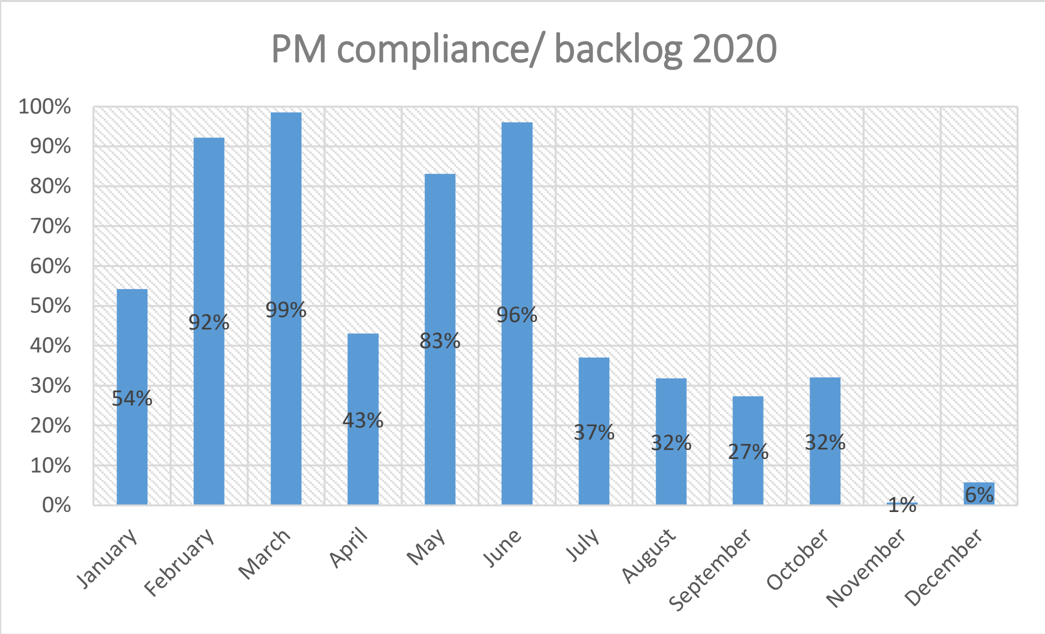

Figure 4. 5. PM Compliance report of the Electrical section for the year 2020

Table 4. 6. Monthly backlogs of the Electrical section for the year 2021

Electrical PM compliance 2021			
Month	Issued	Received	**Backlog (%)**
January	341	82	76
February	325	284	13
March	423	279	34
April	364	149	59
May	300	286	5
June	398	300	25
July	316	286	9
August	385	359	7
September	356	201	44
October	381	360	6
November	375	349	7
December	319	311	3

The bar chart of the monthly backlogs for the year 2021 is presented in Figure **4.7** and shows an improvement in terms of backlogs percentage. Since the implementation of the planning and scheduling process in May 2021, for the first time since 2019, the backlog percentage did not go above 25% for four consecutive months.

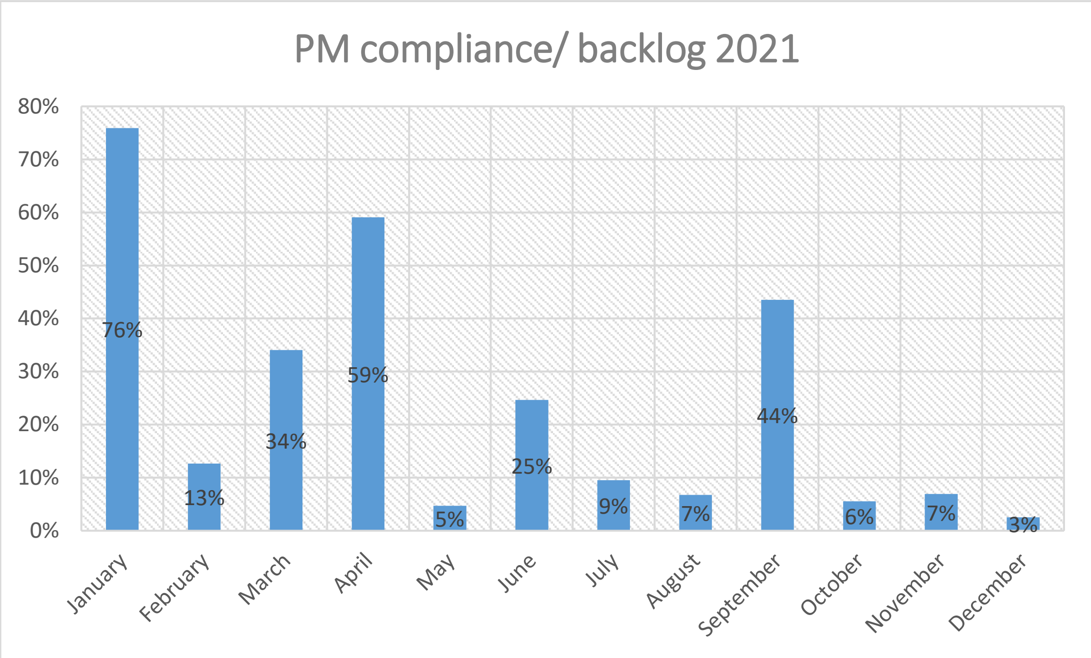

Figure 4. 6. PM Compliance report of the Electrical section for the year 2021

The month of September had a high percentage of backlogs because of the reasons stated in Section **4.1** concerning the production which was stopped for almost half months. Therefore, the PM activities were already generated for the whole month but only those planned between the 13th and 30th were executed on time by the section.

4.3 Duration and Human resource

As discussed in this study, the duration of activities and the human resources allocated to them are affected by the lack of planning and scheduling process. Activities take long and require more human resources when they are not planned or scheduled.

During the on-site visitation period, different activities were analysed in order to compare the duration and human resources allocated in both planned and unplanned cases. The information gathered is shown in Table **4.7**.

These activities were done before and the data was recorded (duration and number of workers assigned). For the experimental part, they were being investigated as explained in section **1.6** to record new data in order to test the influence or effects of the planning and scheduling process on these activities based on the data which was recorded.

Table 4. 7. Activities analysed in both planned and unplanned cases

Activities	**Unplanned**		**Planned**	
	Time (Hours)	Human Resources	Time (Hours)	Human Resources
Daily preventive maintenance	6	5	3	2
Pump command box (wiring)	5	3	3	2
Lamp checking and replacement	2	1	1	1
Middle Voltage Cable preparation	4	3	2	2
Replacement of evacuator motor - 2.2 kW	3	2	1	1
Weightometer calibration (Bagging)	1	2	0.5	1
Installation of transformers	5	3	3	2
Heater replacement in the geezer (Camp)	2	3	1	1
Motor insulation test - 15 kW	3	2	1	1
Laboratory stove troubleshoot	2	2	1	1
Inspection on the filter press	1	2	1	1
Weightometer calibration (Conveyor)	0.5	2	0.5	1
Light command box (wiring)	1	2	1	1
Variable Speed Drive (VSD) installation in the Motor Control Center (MCC)	3	2	2	1
Programmable Logic Controller (PLC) modules installation	2	3	1	2
Replacement of Electric circular saw motor	1	2	1	1
Replacement of Electrical motor - 15kW	4	2	2	1
Replacement of a flight pump	5	3	3	2
Preparation of new panel for skys pump - 160kW	2	3	1	2
Installation of a skys pump - 160kW	3	4	2	2
Preparation of a KSB pump	2	2	1	1
Installation of a KSB pump	3	5	2	3
Replacement of bearings motor- 11kW	2	2	1	1
Replacement of the compressor	4	2	2	1
Insolation test on the Genset 3&4	2	1	1	1
Replacement of plugs in all the containers	3	2	2	1
Installation of a Surge arrester	2	3	1	2
Calibration pH-Meter	0.5	2	0.5	1
Unlock the valve on Kapulo Cyclon	1	1	05	1
Replacement of air distributer on the feed valve of the filter No.1	1	2	1	1
Replacement of the temperature sensor on the ball mill No.2	1	1	0.5	1
Total	**77**	**74**	**43.5**	**42**

Table **4.7** reveals that 77 hours were spent to perform certain activities with 74 workers when the activities were not planned, only 43.5 hours and 42 workers were required to do the same activities when the activities were planned and scheduled. These represent savings of 44% in duration and 43% in human resources allocated.

Figure **4.7** presents for both cases, planned and unplanned, the total duration needed and the human resource allocated to these activities.

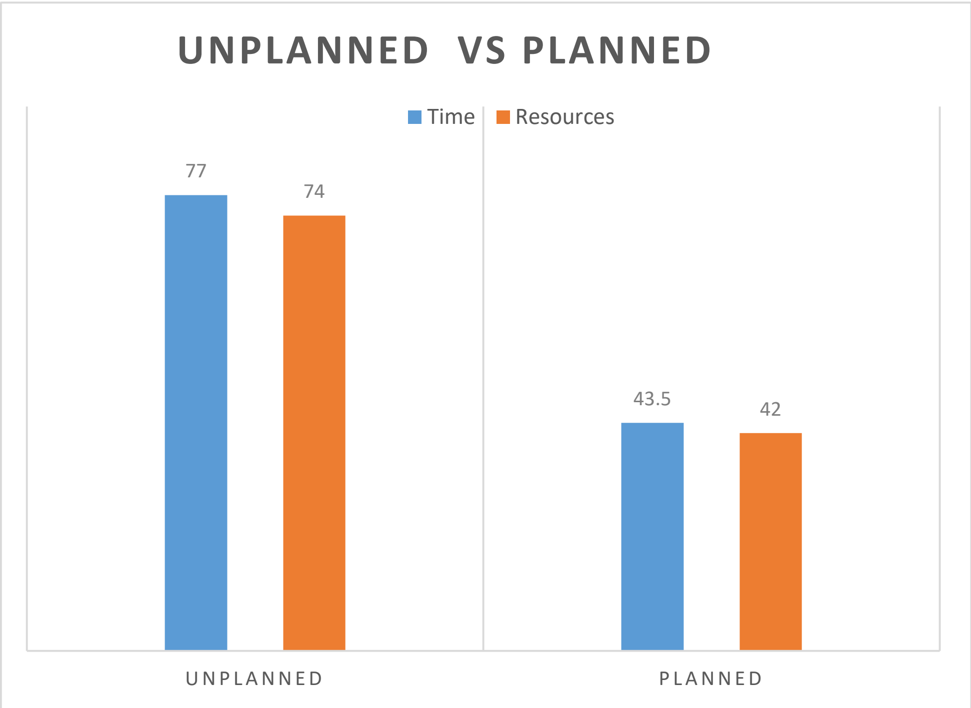

Figure 4. 7. Comparison of duration and human resources for planned and unplanned case

CHAPTER FIVE: DISCUSSION

This chapter of the research presents a summary of the findings analysed in the previous chapter and an interpretation of different figures. The analysed data can be summarised in this section in four different aspects.

5.1 Efficiency of the section

The monthly efficiencies of the Electrical engineering section have been computed for the years 2019, 2020 and 2021. The efficiency has been improved from 73% in December 2019 and 83% in December 2020 to 96% in December 2021.

The section performs well when the efficiency approaches 100%. Therefore, these figures show that December 2021 performed very well compared to the same month of the two previous years. This is one of the effects of the planning and scheduling process implemented in 2021.

5.2 Duration of activities

For the analysed activities listed in Table **4.7**, the total duration was reduced from 77 hours when unplanned to 43.5 hours when planned. This is because when activities are planned, they take less time compared to the case without any prior planning as is discussed in the literature review.

5.3 Backlogs

This research considers backlogs as all maintenance work (preventive maintenance activities) that has been planned and scheduled but not executed. The monthly PM compliance reports have been analysed for the years 2019, 2020 and 2021. The planning section of AMC computes the maintenance backlogs in percentage terms.

The backlogs percentage has been reduced from 57% in January 2019, 54% in January 2020 and 59% in April 2021 to 3% in December 2021 after the implementation of the planning and scheduling process in 2021. This is also one of the effects of a good planning and scheduling process which the standard wants to do not exceed 10% of backlog.

For the first time since 2021, within 4 months, the percentage of backlogs remained below 25%.

5.4 Human resources

For the activities analysed listed in Table **4.7**, the number of human resources was reduced from 74 workers when unplanned to 42 workers when planned. This is because when activities are planned, they may require less human resources compared to the case without prior planning.

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

This last chapter of the research starts with a conclusion of what was done in this study about the effects of planning and scheduling in Electrical engineering; and it ends with some recommendations formulated towards both further research and the company Anvil Mining Congo SA, especially the Electrical engineering and planning section based on the findings.

6.1 CONCLUSION

After the introduction and literature review, methodology and data analysis, and summary of findings, this research ends with a conclusion.

The effects of the planning and scheduling process in Electrical engineering have been assessed, meaning this research met the general objective as well as the specific objectives enumerated in the introduction chapter of this dissertation. First of all, the maintenance planning and scheduling approaches used in the mining industry have been reviewed; then the planning and scheduling system of the Electrical section of Anvil Mining Congo SA was evaluated and compared to the approaches identified in the mining industry to suggest a specific approach to be used and finally the effects of this process on the performances of the section were brought out and evaluated. These objectives were met using the research design shown in Figure **3.1** and the collection procedure in Figure **3.2**.

Therefore, after the analysis of the collected data, it was shown, as predicted in the literature review, that the planning and scheduling process being the only variable parameter, has affected the performances of the Electrical engineering section.

The total duration to complete works of the analysed activities was reduced by 44% while the human resource allocated to the activities were reduced by 43%. The efficiency of the section increased to 96% in December while the Preventive Maintenance backlog was reduced to 3% in December 2021.

The company's Electrical Section is currently implementing a pilot planning and scheduling process after which a decision will be made whether to switch to full scale.

Partial results of this research were also published in the International Journal of Engineering Research and Technology, Volume 10, Issue 11 on the 4th of December 2021 (Kiyanga et al., 2021) as shown in Appendix **E**.

6.2 RECOMMENDATIONS

With regards to the advantages of the planning and scheduling process and its effects in the Electrical engineering domain as shown in this study, some recommendations are formulated towards the company AMC about the Electrical engineering section:

i. To fully implement the suggested approach of planning and scheduling process so that the section can have improved performance compared to the period without planning. These performances include the efficiency of the section, the PM compliance, the duration and human resources allocated to a given work.
ii. To arrange the roast of workers in order to roughly have the same number of electrical engineers every week to ensure their availability on site.
iii. To train the Electrical engineering personnel in planning and scheduling so that they can understand the importance of this process and its benefits for the section, the maintenance department and the company at large.
iv. To recruit one or two people for the planning section to support the work done by the two actual planners who are overloaded.
v. To combine planning and scheduling with either of the maintenance backlog reduction processes discussed in section **2.5** to reduce as much as possible the PM backlog.

To other researchers, further studies can be done taking into consideration different aspects of the planning and scheduling process such as financial aspect, time aspect (since it is a consuming time process), workload aspect to analyse what would be the influence of this process on the company budget and personnel workload.

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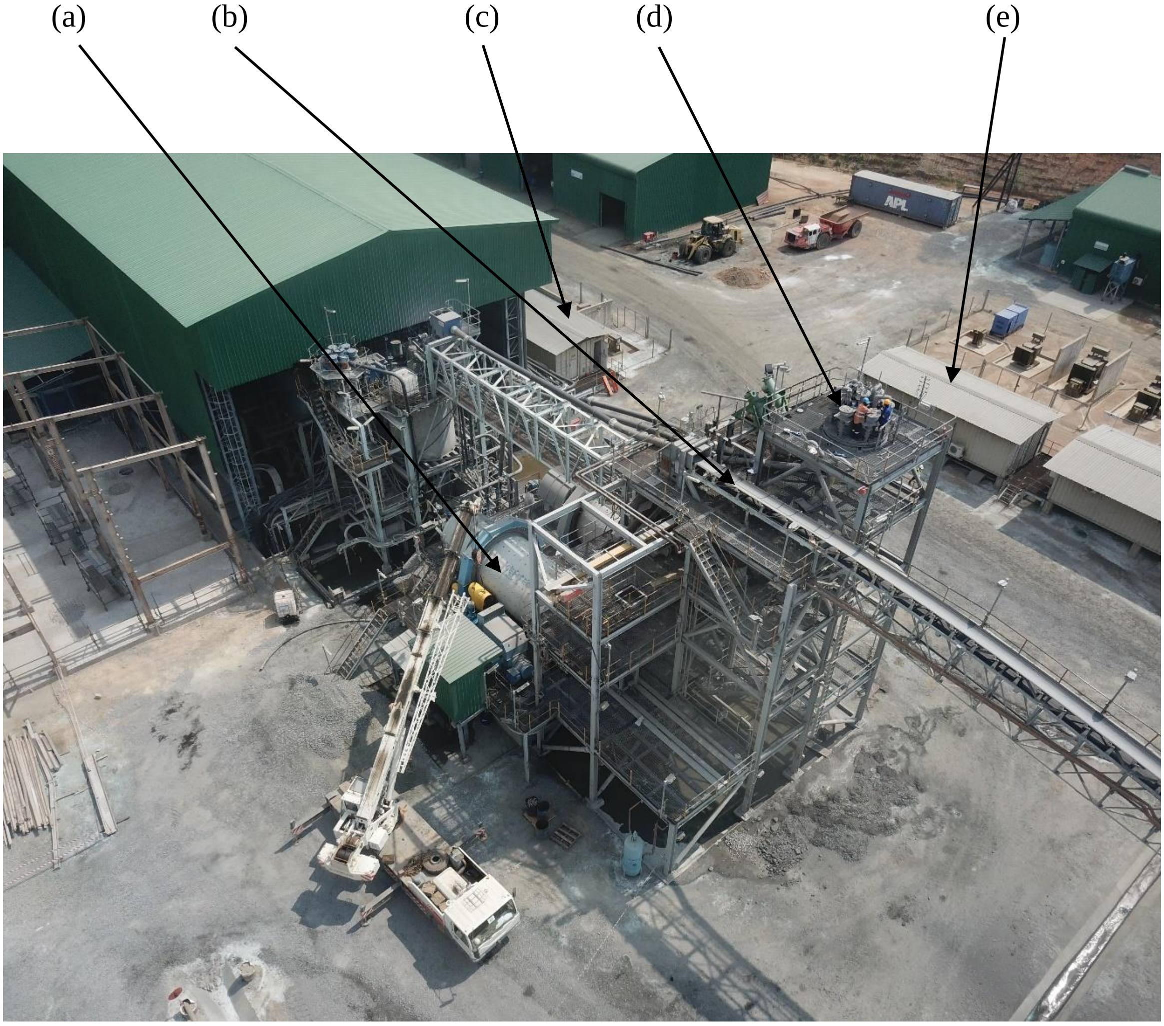
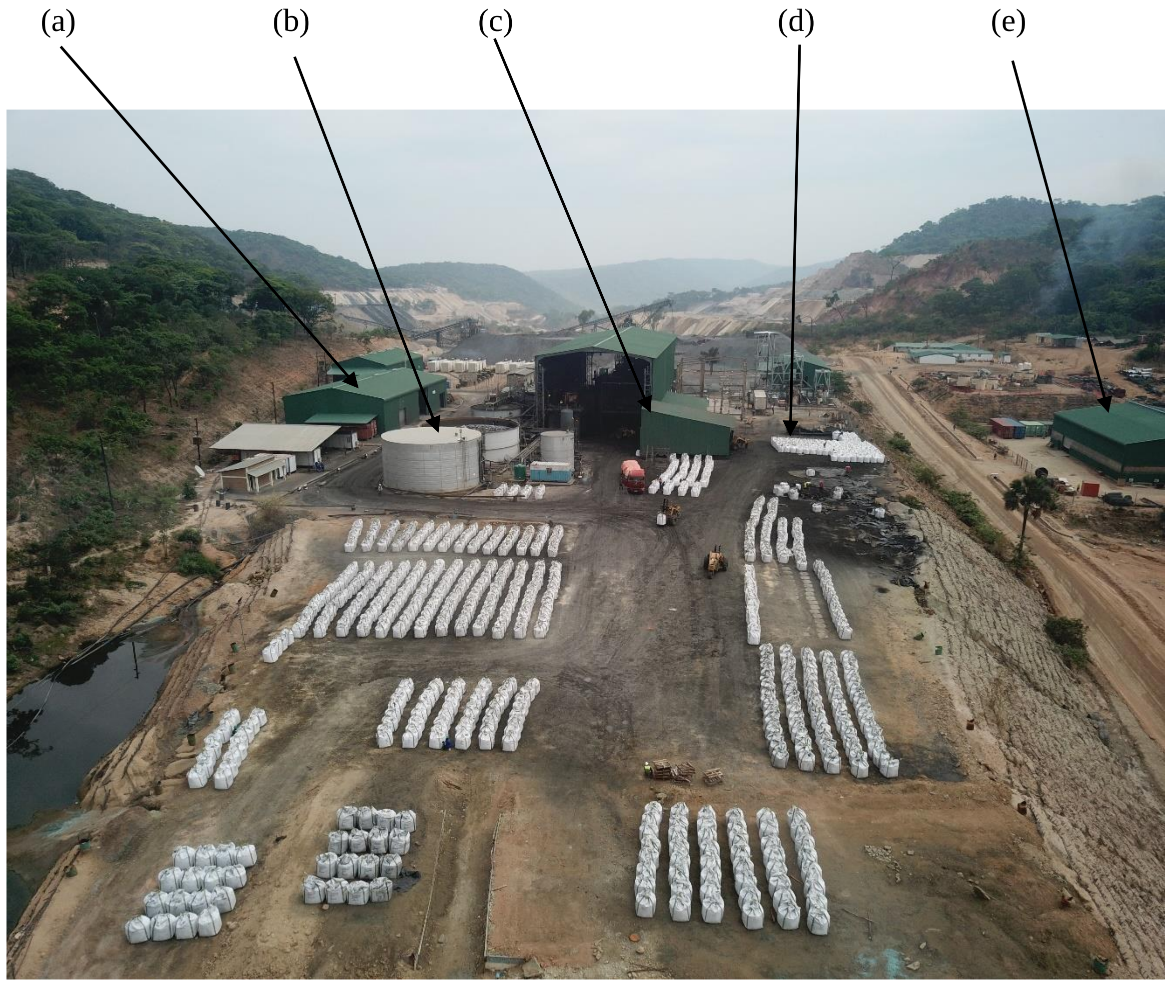
APPENDIX

Appendix A: Pictures of the site



Key:

(a) Ball Mill 01
(b) Conveyor 02 (From the crushing section)
(c) MCC Flotation
(d) Cyclone pump
(e) Control room



Key:

- (a) Mechanical workshop
- (b) Main water tank
- (c) Bagging hall
- (d) Concentrate of Copper
- (e) Warehouse

Appendix B: Detailed data for the monthly efficiencies

B-1: Monthly efficiencies for the year 2019

Year 2019													
		January	February	March	April	May	June	July	August	September	October	November	December
Activities to be done	Week 1	15	15	11	16	15	19	15	13	17	17	17	16
	Week 2	17	17	13	17	18	14	13	15	14	13	16	17
	Week 3	16	12	16	19	19	19	12	10	15	14	13	15
	Week 4	13	15	18	19	17	18	11	15	19	10	14	19
	Total	**61**	**59**	**58**	**71**	**69**	**70**	**51**	**53**	**65**	**54**	**60**	**67**
	Average per week	15.25	14.75	14.5	17.75	17.25	17.5	12.75	13.25	16.25	13.5	15	16.75
Activities done	Week 1	11	12	10	16	13	17	13	11	13	10	13	12
	Week 2	14	15	11	14	12	11	10	9	14	9	13	13
	Week 3	12	10	10	15	15	14	9	8	9	11	11	11
	Week 4	12	11	14	14	11	11	8	11	11	7	12	13
	Total	**49**	**48**	**45**	**59**	**51**	**53**	**40**	**39**	**47**	**37**	**49**	**49**
	Average per week	12.25	12	11.25	14.75	12.75	13.25	10	9.75	11.75	9.25	12.25	12.25
Efficiency (%)		**80**	**81**	**78**	**83**	**74**	**76**	**78**	**74**	**72**	**69**	**82**	**73**

B-2: Monthly efficiencies for the year 2020

Year 2020													
		January	February	March	April	May	June	July	August	September	October	November	December
Activities to be done	Week 1	13	15	18	10	11	17	17	19	23	21	16	14
	Week 2	12	16	17	19	13	15	16	15	18	19	17	19
	Week 3	11	13	16	17	19	12	11	17	21	23	19	17
	Week 4	14	17	12	14	13	15	13	21	19	14	27	21
	Total	**50**	**61**	**63**	**60**	**56**	**59**	**57**	**72**	**81**	**77**	**79**	**71**
	Average per week	12.5	15.25	15.75	15	14	14.75	14.25	18	20.25	19.25	19.75	17.75
Activities done	Week 1	10	13	15	8	7	13	15	16	17	16	13	11
	Week 2	9	13	12	15	10	12	12	13	12	13	14	16
	Week 3	9	11	13	15	15	10	9	14	17	17	14	13
	Week 4	9	13	11	11	8	13	11	16	14	11	20	19
	Total	**37**	**50**	**51**	**49**	**40**	**48**	**47**	**59**	**60**	**57**	**61**	**59**
	Average per week	9.25	12.5	12.75	12.25	10	12	11.75	14.75	15	14.25	15.25	14.75
Efficiency (%)		**74**	**82**	**81**	**82**	**71**	**81**	**82**	**82**	**74**	**74**	**77**	**83**

B-3: Monthly efficiencies for the year 2021

Year 2021													
		January	February	March	April	May	June	July	August	September	October	November	December
Activities to be done	Week 1	12	25	19	13	18	15	16	17	17	18	17	15
	Week 2	11	17	13	24	14	24	19	26	12	16	19	17
	Week 3	16	26	13	21	15	15	23	24	3	18	16	16
	Week 4	17	21	12	25	16	13	21	15	5	15	13	20
	Total	**56**	**89**	**57**	**83**	**63**	**67**	**79**	**82**	**37**	**67**	**65**	**68**
	Average per week	14	22.25	14.25	20.75	15.75	16.75	19.75	20.5	9.25	16.75	16.25	17
Activities done	Week 1	10	22	16	11	17	14	15	16	17	17	16	14
	Week 2	9	15	11	19	13	23	17	24	5	15	18	16
	Week 3	13	21	9	18	13	14	21	23	2	17	15	16
	Week 4	15	17	10	21	15	13	21	15	5	15	12	19
	Total	**47**	**75**	**46**	**69**	**58**	**64**	**74**	**78**	**29**	**64**	**61**	**65**
	Average per week	11.75	18.75	11.5	17.25	14.5	16	18.5	19.5	7.25	16	15.25	16.25
Efficiency (%)		**84**	**84**	**81**	**83**	**92**	**96**	**94**	**95**	**78**	**96**	**94**	**96**

Appendix C: Checklists for Electrical section

C-1: Motors checklist

FLOTATION AREA - 1 OF 2 ____ Feb 2022

Electrical Motors Weekly Checks

Resp. : *Electrical*
Work Type : *PM*
PM Task : *2048*

No.	Equipment Tag	Description	Rated kW	Rated Amp	Type DOL/VSD	Current, Amp	Temp. NDE, (not >70 °C)	Temp. DE (not >70 °C)	Clean Motor	Check Motor Fan	Check unusual noise & vibration	Cable Temp. (L1/L2/L3) @ MCC
1	42-TANK-01	Rougher Conditioning Tank (42-MIXR-01)	37	50,6	DOL							
2	42-CRAN-01	Flotation Area Over Head Crane	0,65	1,3	DOL							
3	42-FTKC-01	Rougher Cell #1 Motor	37	60,9	DOL							
4	42-FTKC-02	Rougher Cell #2 Motor	45	60,9	DOL							
5	42-FTKC-03	Rougher Cell #3 Motor	45	60,9	DOL							
6	42-FTKC-04	Scavenger Cell #1 Motor	45	60,9	DOL							
7	42-FTKC-05	Scavenger Cell #2 Motor	45	60,9	DOL							
8	42-FTKC-06	Scavenger Cell #3 Motor	45	60,9	DOL							
9	42-FTKC-07	Scavenger Cell #4 Motor	45	60,9	DOL							
10	42-FTKC-08	Cleaner 1 Cell #1 Motor	15	21,3	DOL							
11	42-TANK-05	Cleaner 1 & 2 Conditioning Tank (42-MIXR-02)	2	3,63	DOL							
12	42-FTKC-09	Cleaner 1 Cell #2 Motor	15	21,3	DOL							
13	42-FTKC-10	Cleaner 1 Cell #3 Motor	15	21,3	DOL							
14	42-FTKC-11	Cleaner 1 Cell #4 Motor	15	21,3	DOL							
15	42-FTKC-12	Cleaner 1 Cell #5 Motor	15	21,3	DOL							
16	42-FTKC-13	Cleaner 1 Cell #6 Motor	15	21,3	DOL							
17	42-FTKC-14	Cleaner 2 Cell #1 Motor	15	21,3	DOL							
18	42-FTKC-15	Cleaner 2 Cell #2 Motor	15	21,3	DOL							
19	42-FTKC-16	Cleaner 2 Cell #3 Motor	15	21,3	DOL							
20	42-FTKC-17	Cleaner 2 Cell #4 Motor	15	21,3	DOL							
21	42-TANK-10	Cleaner 3 Conditioning Tank (42-MIXR-03)	4	6,35	DOL							
22	42-FTKC-18	Cleaner 3 Cell #1 Motor	15	21,3	DOL							
23	42-FTKC-19	Cleaner 3 Cell #2 Motor	15	21,3	DOL							
24	42-FTKC-20	Cleaner 3 Cell #3 Motor	15	21,3	DOL							
25	42-FTKC-21	Cleaner 3 Cell #4 Motor	15	21,3	DOL							
26	42-FTKC-22	Rougher Cell #1 Dikulushi	22	31,4	DOL							
27	42-FTKC-23	Rougher Cell #2 Dikulushi	22	31,4	DOL							
28	42-FTKC-24	Rougher Cell #3 Dikulushi	22	31,4	DOL							
29	42-FTKC-25	Rougher Cell #4 Dikulushi	30	41,3	DOL							
30	42-FTKC-26	Rougher Cell #5 Dikulushi	22	31,4	DOL							
31	42-FTKC-27	Rougher Cell #6 Dikulushi	22	31,4	DOL							
32	42-FTKC-28	Scavenger Cell #1 Dikulushi	30	41,3	DOL							
33	42-FTKC-29	Scavenger Cell #2 Dikulushi	30	41,3	DOL							
34	42-FTKC-30	Scavenger Cell #3 Dikulushi	30	41,3	DOL							
35	42-FTKC-31	Scavenger Cell #4 Dikulushi	30	41,3	DOL							

Comments/Remarks

	Name & Signature	Date	Mark	Tools:
Field Technician		___/Feb/2022	*Aark : Except with values* *Good* /	*Temp. Gun*
Area Supvr./Sup		___/Feb/2022	*Bad* X	*Clamp Mete*

Appendix D: PM Work orders

D-1: PM work order for transformers

```
Anvil Mining Congo - Kapulo              Date: 03-FEB-2022 10:54:16  Page:     1

                    Plant Work Order Sheet

W/O Number    : 204743              Status: Complete     Scheduled : 07-JAN-2022
Parent        : 15-TRF               TRANSFORMERS
Plant Item    : 15-TRF-01            TRANSFORMER#01(0.4/11,2500KVA)
Cost Centre   : 41222344   Power House                   Issued      : 16-JAN-2022
Plt Type Codes: GENS                                     Planned By:
Location      :
Sub-Location  :            Branch Code :                 Priority    : 3
Responsibility: SME        Maint Electrical SupLast Completed W/O   : 14-JAN-2022
Work Type     : PM         Preventative MaintenLast Completed W/O #: 204797
                                     PM Task: 4007                       7 DAYS
Parts :                                                  Drawings    :
      :                                                  Section     : POWERHOUSE
Tools :                                                  Draw Ref.   :
                                     Last Comp Task Date :  14-JAN-2022
                                     Last Comp Task W/O  :  204797
-------------------------------------------------------------------------------
Work Description : Weekly Inspection of Transformer
                 : a. Visual Check of Oil coloration found in bochuls Relay
                 :    glass.
                 : b. Visual check of Silica gel dessicant Coloration
                 :   - Color change from blue to orange
                 :   - Color change from oranget to Green
                 : c  Check Oil level and leakage
                 : d  Oil winding and temperature
                 :
                 : Comment:...................................................
                 : ...........................................................
                 : ...........................................................
-------------------------------------------------------------------------------
Created By       : Order raised by isidorek on 30-Dec-2021 at 09:14.
Work Carried Out :
                 : ________________________________________________
                 :
                 : ________________________________________________
                 :
                 : ________________________________________________
                 :
                 : ________________________________________________

Parts Used       :
                 : ________________________________________________
                 :
                 : ________________________________________________

Work done by     : ________________________________________________

Date Completed   : __________________

Labour Hours     :-
      Other Labour Type               Used:                         ________
```

D-2a: PM work order for weightometers (Recto)

Anvil Mining Congo - Kapulo   Date: 03-FEB-2022 10:51:58   Page: 1

Plant Work Order Sheet

W/O Number : 204933   Status: Complete   Scheduled : 04-JAN-2022
Parent : 21   CRUSHING
Plant Item : 21-WEIG-02   CRUSHED ORE WEIGHTOMETER
Cost Centre : 41222030   CRUSHING   Issued : 15-JAN-2022
Plt Type Codes: WEIG   Planned By:
Location :
Sub-Location :   Branch Code :   Priority : 3
Responsibility: SMI   Maint Instruments SuLast Completed W/O : 18-JAN-2022
Work Type : PM   Preventative MaintenLast Completed W/O #: 204974
Phy-Location :
PM Task: 2011   7 DAYS
Parts :   Drawings :
:   Section : CRUSHING
Tools :   Draw Ref. :
Last Comp Task Date : 18-JAN-2022
Last Comp Task W/O : 204974

Work Description : Weekly Maintenance Crushed Ore Weightometer & Speed Sensor
:
: 1) Weightometer
:
: 1. Inspect platform and ensure no foreign material jammed.
: 2. Inspect speed tachometer and ensur it is perpendicular
: to the running line of the conveyor.
: 3. Ensure tachometer wheel is not slipping.
: 4. Ensure Tachometer cables are tight and well connected.
: 5. Ensure Load cell cables are tight and well connected.
: 6. Ensure Load cell junction box is lealed, tight and
: fastened
: 7. Ensure all glands are tight.
: 8. Wipe Monitor and ensure cleanness of display.
: 9. Ensure panel door is closed and sealed properly
: 10.Open indicator panel and ensure no presence of foreign
: material
: 11.Ensure all connections are tight.
: 12.Ensure supplied voltage are adequate.
: 13.Ensure display is on and all power LED are on.
:
: I. Ensure conveyor is running empty and record kg/m reading
: II.Ensure conveyor is running empty and record tph reading.
: III.Ensure conveyor is running empty and perform dynamic
: zero calibration (as per calibration procedure)
: IV.At the end of the zero calibration, note down the
: " % Error" and accept or reject the correction as per
: calibration procedure.
: V. If the correction has been accepted, note the Old Bit
: Zero and the new bit Zero.
: VI. Press Run to return normal operation
:
: 2) Speed Sensor
:

D-2b: PM work order for weightometers (Verso)

:
:
:
:
:

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Plant Work Order Sheet

W/O Number : 204933 **(Continued)** Status: Complete   Scheduled : 04-JAN-2022

: Comment:..
: ....
: ....

Created By : Order raised by isidorek on 30-Dec-2021 at 10:53.

Work Carried Out :
: ____________________
:
: ____________________
:
: ____________________
:
: ____________________

Parts Used :
: ____________________
:
: ____________________

Work done by : ____________________

Date Completed : ____________

Labour Hours :-

Other Labour Type   Used: __

D-3: PM work order for generators

Anvil Mining Congo - Kapulo Date: 03-FEB-2022 13:28:25 Page: 1

Plant Work Order Sheet

W/O Number : 205522 Status: In Progress Scheduled : 23-JAN-2022
Parent : 15 POWER SUPPLY
Plant Item : 15-GEND-01 GENERATOR SET #1
Cost Centre : 41222344 Power House Issued : 30-JAN-2022
Plt Type Codes: GENS Planned By:
Location :
Sub-Location : Branch Code : Priority : 3
Responsibility: SPH Power Station SupervLast Completed W/O : 12-JAN-2022
Work Type : PM Preventative MaintenLast Completed W/O #: 205565
Phy-Location : POWER SUPPLY
PM Task: 4001 250 HU
Parts : Drawings :
: Section : POWERHOUSE
Tools : Draw Ref. :
Last Comp Task Date : 05-JAN-2022
Last Comp Task W/O : 205200

Work Description : 250 HOUR SERVICE SCHEDULE
:
: 1. Drain engine oil and refill with 15w-40 oil.
: 2. Replace oil filter x6
: 3. Replace fuel filter x1-(P/N 9010-328) or SH429B/4
: 4. Clean air filter/change if necessary x2-(P/N 10000-12122)
: 5. Inspect air filter service indicator and report if not in
: GREEN ZONE
: 06. Inspect/adjust/replace vee belts
: 07. Check fan blade to cover clearance (6 12.5mm)
: 08. Grease fan drive bearing
: 09. Check all hoses and clamps
: 10. Inspect annunciator panel
: 11. Check battery water level. Top up if necessary
: 12. Clean/Replace crankcase breather
: 13. Clean radiator with degreaser
: 14. Clean generator with degreaser
:
:

Safety Notes : **MECHANICAL SAFETY DURING MAINTENANCE AND REPAIR**
:
: **1 Personal Protective Equipment (PPE) should be used at**
: **all times.**
:
: **2 Be sure all mechanical components are brought to a zero**
: **energy state including all**
: **spring driven devices, cylinders, accumulators, drive**
: **shafts, pulleys, rollers, gears, etc.,**
:
: **3 Never attempt to perform repair, maintenance, or**
: **troubleshooting work on or in proximity to**
: **energized mechanical components.**
:
: **4 For repair, maintenance or troubleshooting work,**
: **disconnect all devices from electric, pneumatic and**
: **hydraulic power sources and follow lockout procedures.**
:
: **5 Use the proper equipment.**

Appendix E: Published Article

Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 11, November-2021

Investigation into the Effects of Daily Planning and Scheduling in Electrical Engineering within Mining Companies, case of Anvil Mining Congo SA

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***Abstract*— The planning and scheduling process is an inevitable step in any organization. This research investigated its effects in the electrical section of Anvil Mining Congo SA. In this company, planning, and scheduling, especially on equipment, focuses on preventive maintenance and not on activities related to repair, replacement and installation works. This research aimed to evaluate the changes in the performance of the electrical engineering section which currently lacks the daily planning and scheduling process. A quantitative approach with observations and desk study as instruments for data collection was used. The collected data included the duration (time) and the human resources allocated to particular activities. Data with and without daily planning and scheduling were compared to evaluate the changes in the section's performance over a study period of 30 months. After implementing the daily planning and scheduling process, the total duration to complete works of the analyzed activities was reduced by 45% while the human resources allocated to the activities were reduced by 46%. The efficiency of the section increased from 74% in August 2019 and 82% in August 2020 to 95% in August 2021. The preventive maintenance backlog reduced from 76% in January 2021 to 7% in August 2021. The company's electrical section is currently implementing a pilot planning and scheduling process after which a full-scale is envisaged to be implemented.**

Keywords*— *Backlog; Efficiency; Human Resources; Planning; Scheduling;

I. INTRODUCTION

Planning and scheduling are important in the whole industrial world. They are among the first steps taken when it comes to performing activities such as maintenance, investment, recruitment, and so forth.

Planning involves establishing the organizational objectives and deciding what actions need to be taken to achieve them [1]. After establishing the organizational objectives, the scheduling step follows. Scheduling is the allocation of resources to tasks over given periods to optimize one or more objectives [2]. It is a decision-making process that is used regularly in many manufacturing and service industries.

The planning and scheduling process reduces or eliminates uncertainties, improves efficiency, facilitates process control, and puts focus on objectives by providing a better understanding [3]. Concerning the mining industry, planning and scheduling improve resource utilization to ensure resources are used effectively [4]. Planning and scheduling can be short, medium, or long-term. In the literature, limited research has been done on a daily (short-term) as compared to medium and long-term planning and scheduling [5] [6]. The existing literature also focuses on preventive maintenance (PM) and not on daily activities such as breakdown maintenance (BM).

Using a priority function, [7] developed a planning and control system for use in a foundry. They stated that the PM capacity (workforce) available the next day was the difference between the total maintenance capacity and the BM required workforce. Reference [8] noted that schedules depend on plans and that in dynamic environments such as the ones presented by daily operations in the mining industry, rather than software tools, human beings develop schedules using their knowledge and experience in the particular domain. In the literature review on trends in turnaround (planned shutdown) maintenance planning, [9] defined short-term planning as one with a period of four to ten weeks. Reference [5] restricted the literature review on short-term planning of open-pit mines activities to periods of at least one week to at most one to two years. Daily planning involving equipment selection and truck dispatch was outside the scope of the review. These studies show the lack of research not only on short-term planning and scheduling in general but also on the daily planning and scheduling of activities in the mining industry.

This study investigated the daily planning and scheduling process in the electrical engineering section of Anvil Mining Congo SA in the Democratic Republic of Congo (DRC). This is because the planning and scheduling process has fundamental effects on the performance indicators of the section. Only 4 of the indicators were considered in the study. These were the completion duration of activities (jobs), the efficiency of the section, the human resources allocated to activities, and the preventive maintenance compliance.

The study aimed to assess the effects of daily planning and scheduling in the electrical engineering section within a mining company. This was to be attained by reviewing the maintenance planning and scheduling approaches used in the mining industry, evaluating the planning and scheduling system of the electrical engineering section of Anvil Mining Congo SA and comparing it to the approaches previously identified, and evaluating the effects of daily planning and scheduling process on the performances of the electrical engineering section.

II. BACKGROUND

A. Planning

Planning is an important concept in any organization and it has been defined by different authors. Planning is the process of setting objectives and determining how to accomplish them and it involves deciding exactly what needs to be accomplished and how best to go about it [11]. Planning is the determination of what needs to be done, by whom, and by when should one's assigned responsibility be fulfilled [12]. It is looking ahead and drawing future courses of action to be followed. It is a systematic activity that determines when, how, and who is going to perform a specific job [13].

Planning is important because it helps organizations to achieve their objectives; it is a prerequisite not only for achieving success but also for surviving in a complex and competitive world [14]. The planning process has an impact on the company which is doing it in the way that it affects the performance, facilitates control, and helps the company in the decision-making process [13].

Planning is done in 9 different steps as stated by [3]; (1) Clear definition of the objectives, (2) Establishment of the project scope, (3) Dividing and subdividing of the project scope into major pieces and work packages (Work Breakdown Structures), (4) Definition of specific activities that need to be performed for each work package to accomplish the project objectives, (5) Graphically portraying of activities in the form of network diagrams showing sequences and interdependencies, (6) Making time estimate for each activity, (7) Estimation of other resources for each activity, (8) Calculation of the project schedule and budget to determine whether the project can be completed within the required time, with the allocated funds and other resources, and (9) Adjustment of the project scope, activity time estimates, and resource estimate till a realistic baseline plan is achieved.

There are four types of planning which include strategic planning, tactical planning, operational planning, and functional planning [11]. Daily planning (which is at the centre of this study) falls under operational planning.

B. Scheduling

Scheduling is a concept that is most of the time attached to planning. It is the establishing of times at which to begin and complete each event or operation comprising a procedure [15]. It can also be defined as the determination of the timing and sequence of operations in the project and their assembly to give the overall completion time [16] or the process of describing in detail which activities must be performed and how the organization's resources should be utilized to satisfy a given plan [17].

According to the size of the company and the business it is involved in, 5 types of scheduling have been enumerated: baseline schedules, detailed schedules, master production schedules, look ahead schedules, and weekly schedules [18].

Scheduling is done in 6 different steps as stated in [19]: (1) Planning and schedule management, (2) Definition of activities, (3) Sequencing of activities, (4) Estimation of activity resources, (5) Estimation of activity duration, and (6) Development of schedules.

C. Planning and scheduling in the mining industry

This research focused on the planning and scheduling process in the electrical engineering section which falls under the maintenance department as far as the mining industry is concerned. In this regard, maintenance is an act that includes keeping, preserving, and protecting a machine [20]. It is defined as efforts taken to keep the condition and performance of a machine always like its condition and performance when it is new [21].

Different approaches have been developed to know how maintenance can be performed to ensure equipment reach or exceed its design life [10]. These approaches include reactive maintenance, preventive maintenance, predictive maintenance, and reliability-centred maintenance [15]. Besides these, modern approaches are also used nowadays which include lean maintenance and six sigma maintenance. Six sigma maintenance is the application of six sigma principles in maintenance that focuses on reducing the variation in production while the application of the lean principle in a maintenance environment is called lean maintenance [15].

For a production-based company such as a mining company, 6 steps are necessary to plan and schedule an activity [10], (1) Knowledge base, (2) Job investigation at the site, (3) Identification and documentation of the work, (4) Development of the repair plan, (5) Preparation of tools and facilities list, and (6) Estimation of the time required to do the job. For Tenke Fungurume Mining, only 5 steps are included in the planning and scheduling process [22]: (1) Understanding of the job, (2) Area of work, (3) Proposition of techniques, (4) Time and resources, and (5) safety and permission. Concerning the mining industry in general, 6 steps are enough according to [18]: (1) Equipment identification work, (2) Presence of a support network, (3) Definition of an effective program, (4) Use of information efficiently, (5) Establishment of organization levels, and (6) Taking of measurements and evaluation.

III. METHODOLOGY

A. Definition of the case study

Anvil Mining Congo SA is found in the Pweto district in the DRC. The company is mainly involved in copper mining. For the company, the planning and scheduling process is the responsibility of the maintenance department which is one of the company's most important departments. The department has the role of ensuring that all sets of equipment are in good working conditions always to allow smooth mining operations. The maintenance department of Anvil Mining Congo SA is organized as shown in Fig. 1.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 11, November-2021

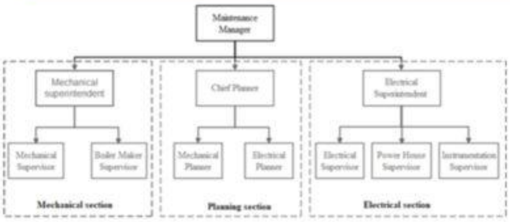

Figure 1. Organization chart of the maintenance department

Here only the planning and electrical engineering sections were considered. The electrical engineering section is important because it is responsible for generating electricity for the company which does not have any other external source of electrical power. The power that supplies the whole plant is produced by the electrical section through diesel generators.

The role of the planning section is to plan and schedule all the activities concerning maintenance, from the stock management to the work plans and schedules. This section comprises 3 people. 1 person from the electrical section, 1 from the mechanical section, and 1 data clerk. For maintenance management, the company uses PRONTO XI as the computerized maintenance management system.

The planning section gathers daily equipment function information to generate the monthly PM activities. The information includes electric current and temperature for motors and ball mills, running hours, oil and fuel consumption for the generators, and temperature for transformers, etc. Designed checklists are used to collect these data based on the parameters to measure for each piece of equipment.

The maintenance activities undertaken by the electrical section are supposed to come from the planning section. After the reception of a job request, the planning section generates a work order using PRONTO XI software so that the job is recorded in the system. This makes it easy to evaluate the performance of the section based on the work performed against the planned or scheduled work. However, in the current practice, some of the job requests are given directly to the electrical section. These jobs are only taken to the planning section, from the electrical engineering section, after execution. In some cases, the planning section is not even informed about the jobs. This makes the job of the planning section hard because it is difficult to evaluate the performance of the section in particular and the maintenance department in general.

In the electrical engineering section, the planning and scheduling process ends with a list of activities to be done per day which includes neither availability of human resources nor the preparation of tools, equipment, or time estimation for the activities. A comparison of Anvil Mining Congo SA and other production-based industries is shown in Table 1.

TABLE 1. COMPARISON OF THE PLANNING AND SCHEDULING APPROACHES USED IN PRODUCTION AND MINING INDUSTRIES

	Production-based company (Kumar & Suresh, 2008)	**Tenke Fungurume Mining (Christian, 2017)**	**Mining industries (Frieser, 2020)**	**Anvil Mining Congo SA**	
				PM activities	***Daily activities***
1	Knowledge base	Understanding of the job	Equipment identification	Area identification	Equipment/ machine identification
2	Job investigation at the site	Area of work	Have a support work	Equipment identification	Execution
3	Identification and documentation of the work	Proposition of techniques	Define an effective program	Generation of PM task	
4	Development of repair plan	Estimation of time and resources	Use past information efficiently	Techniques proposition	
5	Tools and facilities list	Safety and permission	Establish organization levels	Safety considerations	
6	Estimation of time required	Execution	Execution	Execution	
7	Execution		Evaluate and perform measurements		

Table 1 shows that for Anvil Mining Congo SA, concerning the PM activities which are planned by the planning section, the planning and scheduling process involves five steps before the execution of the activities. But for the electrical engineering section, only the identification of the machine/ equipment is required before the execution of the activities. Therefore, activities are executed without any prior planning.

This lack of daily planning and scheduling affects firstly, the PM compliance which showed 59% of backlogs in April 2021 (Table 4) the month at the end of which the pilot planning and scheduling was implemented. This level of backlogs is against the maintenance standard which requires that backlogs should not exceed 10% [10]. Secondly, the activities take more time and require a lot of human resources to be completed compared to the case if there was prior planning and scheduling. Lastly, the efficiency of the section is also affected by the lack of planning and scheduling. The section report showed the highest efficiency of 83% in April 2021 (Table 4).

The research used a quantitative approach to achieve its objectives. It used observation and desk study as instruments for data collection. Interviews were used for information clarification.

B. Data collection process

The data collection procedure, as shown in Fig. 2, started with the job requests received at the section per day. For a given job request, the first step was to know if the job has been done before. If the job has never been done before, the second step was to apply the planning and scheduling process. If the job has been done before, not only was the planning and scheduling process implemented on it but also the recorded data (time spent and human resources allocated when the job was done) were collected through document review.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 11, November-2021

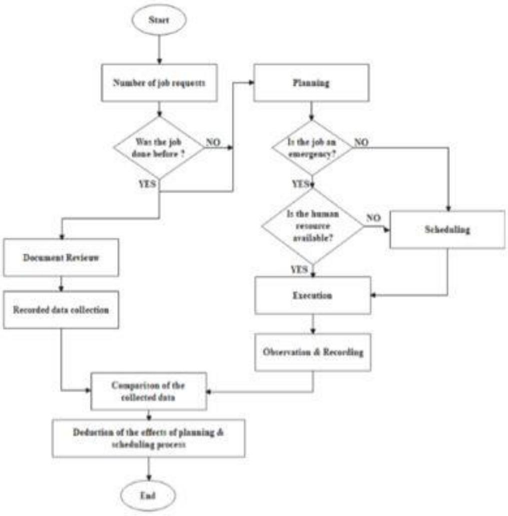

Figure 2. Data collection procedure

Having two collected data sets, respectively from the document review (without any prior planning and scheduling) and the records for jobs done after the planning and scheduling process, the next step was the comparison of these data sets to deduce the difference and highlight the effects of the planning and scheduling process.

Based on the emergency and the availability of the human resources, the activity (job) was either planned to be executed or scheduled for a suitable day. Then after the execution of the activity, the time spent and the human resources allocated to the activity were recorded.

C. The suggested planning and scheduling process

The research idea was based on the theory of planning and scheduling which states that planning improves efficiency and scheduling is well done if realistic estimates are applied [24]. This is because proper planning reduces the risk of time overruns, enhances outcome quality, and improves operational safety [9].

The planning and scheduling process suggested to the electrical engineering section was the one established by [15] for a production-based company with an aspect of scheduling and safety. This process includes 9 steps: (1) Knowledge base, (2) Job investigation at the site, (3) Emergency assessment, (4) Identification and documentation of the work, (5) Resources availability assessment, (6) Development of repair plan, (7) Tool and facilities list, (8) Estimation of time required, and (9) Safety considerations.

IV. DATA ANALYSIS AND RESULTS

A. The efficiency of the section

The efficiency of the section is computed as a ratio of the number of activities done over the number of activities that were supposed to be done, expressed as a percentage, as shown in (1):

$$\eta = {}^{n}/_{N} \qquad (1)$$

η: efficiency of the section
n: number of activities done
N: number of activities issued

The efficiency of the electrical engineering section was computed for the years 2019, 2020, and from January to August 2021 to compare the figures within the period with and without the planning and scheduling process. The electrical engineering section monthly efficiencies for 2019 are shown in Table 2. The table shows that for the year 2019, the maximum efficiency was 83% and it occurred in April while the minimum was 69%. This occurred in October. For the year 2020, the monthly efficiencies were collected from reports and are shown in Table 3.

TABLE 2. SECTION MONTHLY EFFICIENCIES FOR 2019

	Number of activities done (n)	Number of activities issued (N)	Efficiency (%)
January	49	61	80
February	48	59	81
March	45	58	78
April	59	71	83
May	51	69	74
June	53	70	76
July	40	51	78
August	39	53	74
September	47	65	72
October	37	54	69
November	49	60	82
December	49	67	73

TABLE 3. SECTION MONTHLY EFFICIENCIES FOR 2020

	Number of activities done (n)	Number of activities issued (N)	Efficiency (%)
January	37	50	74
February	50	61	82
March	51	63	81
April	49	60	82
May	40	56	71
June	48	59	81
July	47	57	82
August	59	72	82
September	60	81	74
October	57	77	74
November	61	79	77
December	59	71	83

For the year 2020, the maximum efficiency of 83% occurred in December, while the minimum efficiency of 71% occurred in May as shown in Table 3.

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ISSN: 2278-0181
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The monthly efficiencies for the year 2021 are sown in Table 4. For the first time since 2019, the efficiency of the electrical engineering section reached 92% in May 2021. This increase in efficiency was attributed to the effect of the implemented daily planning and scheduling process which began in May 2021 because that is the only parameter that changed. This increase in the section's efficiency verifies the theory (discussed earlier) which says planning and scheduling improve efficiency.

B. Duration and human resources

The collected data sets were analyzed to compare the duration and human resources allocated to different activities under both planned and unplanned conditions. Fig. 3 shows that 41.5 hours were required to perform certain activities with 39 workers when they were not planned. However, 23 hours and 21 workers were required to do the same activities when they were planned and scheduled. This represents savings of 45% in the duration and 46% in human resources.

TABLE 4. SECTION MONTHLY EFFICIENCIES FOR 2021

	Number of activities done (*n*)	Number of activities issued (*N*)	Efficiency (%)
January	47	56	84
February	75	89	84
March	46	57	81
April	69	83	83
May	58	63	92
June	64	67	96
July	74	79	94
August	78	82	95

Figure 3. Unplanned activities vs planned activities

C. PM Compliance

PM compliance is monitored in terms of the backlog, which is the percentage of the unexecuted PM activities against the issued (planned) PM activities. It is computed using (2):

$$B = 1 - \left({}^{R}/_{I}\right) \tag{2}$$

B: Backlog
R: PM Activities executed
I: PM activities issued

PM compliance information in reports from the year 2019 to 2021 was collected. Table 5 presents the electrical engineering section PM monthly compliance levels for the year 2019. Table 5 shows that for July and August, backlogs were 100%. This happened because the section was working on a project of adding a new unit in the plant and during this same period, more than 2 planned shutdowns were supposed to be done. Therefore, the section did not have enough time for the PM activities (shutdowns). For the year 2020, the PM monthly compliance levels are shown in Table 6.

TABLE 5. PM MONTHLY COMPLIANCE LEVELS FOR 2019

Month	Number of PM activities issued (*I*)	Number of PM activities executed (*R*)	Backlog (*B*) (%)
January	248	107	57
February	135	57	58
March	44	23	48
April	104	78	25
May	192	140	27
June	192	98	49
July	135	0	100
August	112	0	100
September	181	16	91
October	386	356	8
November	438	306	30
December	429	309	28

TABLE 6. PM MONTHLY COMPLIANCE LEVELS FOR 2020

Month	Number of PM activities issued (*I*)	Number of PM activities executed (*R*)	Backlog (*B*) (%)
January	345	158	54
February	270	21	92
March	335	5	99
April	244	139	43
May	373	63	83
June	352	14	96
July	329	207	37
August	383	261	32
September	380	276	27
October	293	199	32
November	284	282	1
December	419	395	6

Table 6 shows that in November and December 2020, the section performed very well in terms of backlogs as shown in Table 6. Planners' explanations for these exceptionally high compliance levels were that there were low workloads during the period covering those months.

The PM compliance levels for 2021 (Table 7), show an improvement in terms of backlogs. After the implementation of the planning and scheduling process in May 2021, for the first time since 2019, the backlog percentage did not go above 25% for 4 consecutive months.

TABLE 7. PM MONTHLY COMPLIANCE LEVELS FOR 2021

Month	Number of PM activities issued (*I*)	Number of PM activities executed (*R*)	Backlog (*B*) (%)
January	341	82	76
February	325	284	13
March	423	279	34
April	364	149	59
May	300	286	5
June	398	300	25
July	316	286	9
August	385	359	7

V. CONCLUSION

The study investigated the daily planning and scheduling process of Anvil Mining Congo SA and the effects of this process on the complete duration of activities (jobs), the efficiency of the section, the human resources allocated to activities and the preventive maintenance compliance. For the investigation, only the planning and scheduling process constituted a change in the daily maintenance approach of the electrical engineering section of Anvil Mining Congo SA.

The study showed, as predicted in the literature, that with the planning and scheduling process, being the only variable parameter, the performance of the electrical engineering section was greatly affected. Within two months, after implementing the planning and scheduling process, the total duration to complete works of the analyzed activities was reduced by 45% while the human resources allocated to the activities were reduced by 46%. The efficiency of the section increased from 74% in August 2019 and 82% in August 2020 to 95% in August 2021. The preventive maintenance backlog reduced from 76% in January 2021 to 7% in August 2021. The company's electrical engineering section is currently implementing a pilot planning and scheduling process after which a decision will be made on whether to switch to full scale or not.

ACKNOWLEDGEMENT

The researchers are thankful to the company Anvil Mining Congo SA's maintenance department for providing the necessary data for this research. This research was funded by the first author.

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Appendix F: Ethical clearance approval

THE UNIVERSITY OF ZAMBIA

DIRECTORATE OF RESEARCH AND GRADUATE STUDIES

Great East Road Campus | P.O. Box 32379 | Lusaka 10101 | **Tel:** +260-290 258/291 777
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RESEARCH DEPARTMENT

APPROVAL OF STUDY

23rd August, 2020.

REF NO.NASREC-2020-JUL-002

Christian Ngoie Kiyanga,
The University of Zambia
School of Engineering,
Department of Agricultural Engineering,
P.O. Box 32379.
LUSAKA.

Dear Mr. Kiyanga,

RE: "EFFECTS OF PLANNING AND SCHEDULING IN ELECTRICAL ENGINEERING WITHIN MINING COMPANIES, CASE OF ANVIL MINING CONGO"

Reference is made to your protocol dated as captioned above. NASREC resolved to approve this study and your participation as Principal Investigator for a period of one year.

Review Type	Ordinary Review	Approval No. NASREC-2021-JUL-002
Approval and Expiry Date	Approval Date: 23rd August, 2021	Expiry Date: 22nd August, 2022
Protocol Version and Date	Version - Nil.	22nd August, 2022
Information Sheet, Consent Forms and Dates	• English.	To be provided
Consent form ID and Date	Version - Nil	To be provided
Recruitment Materials	Nil	Nil
Other Study Documents	Questionnaire.	
Number of Participants Approved for Study		

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Specific conditions will apply to this approval. As Principal Investigator it is your responsibility to ensure that the contents of this letter are adhered to. If these are not adhered to, the approval may be suspended. Should the study be suspended, study sponsors and other regulatory authorities will be informed.

Conditions of Approval

- No participant may be involved in any study procedure prior to the study approval or after the expiration date.

- All unanticipated or Serious Adverse Events (SAEs) must be reported to NASREC within 5 days.

- All protocol modifications must be approved by NASREC prior to implementation unless they are intended to reduce risk (but must still be reported for approval). Modifications will include any change of investigator/s or site address.

- All protocol deviations must be reported to NASREC within 5 working days.
- All recruitment materials must be approved by NASREC prior to being used.

- Principal investigators are responsible for initiating Continuing Review proceedings. NASREC will only approve a study for a period of 12 months.

- It is the responsibility of the PI to renew his/her ethics approval through a renewal application to NASREC.

- Where the PI desires to extend the study after expiry of the study period, documents for study extension must be received by NASREC at least 30 days before the expiry date. This is for the purpose of facilitating the review process. Documents received within 30 days after expiry will be labelled "late submissions" and will incur a penaltyfee of K500.00. No study shall be renewed whose documents are submitted for renewal 30 days after expiry of the certificate.

- Every 6 (six) months a progress report form supplied by The University of Zambia Natural and Applied Sciences Research Ethics Committee as an IRB must be filled in and submitted to us. There is a penalty of K500.00 for failure to submit the report.

- When closing a project, the PI is responsible for notifying, in writing or using the Research Ethics and Management Online (REMO),both NASREC

- and the National Health Research Authority (NHRA) when ethics certification is no longer required for a project.

- In order to close an approved study, a Closing Report must be submitted in writing or through the REMO system. A Closing Report should be filed when data collection has ended and the study team will no longer be using human participants or animals or secondary data or have any direct or indirect contact with the research participants or animals for the study.

- Filing a closing report (rather than just letting your approval lapse) is important as it assists NASREC in efficiently tracking and reporting on projects. Note that some funding agencies and sponsors require a notice of closure from the IRB which had approved the study and can only be generated after the Closing Report has been filed.

- A reprint of this letter shall be done at a fee.

- All protocol modifications must be approved by NASREC by way of an application for an amendment prior to implementation unless they are intended to reduce risk (but must still be reported for approval). Modifications will include any change of investigator/s or site address or methodology and methods. Many modifications entail minimal risk adjustments to a protocol and/or consent form and can be made on an Expedited basis (via the IRB Chair). Some examples are: format changes, correcting spelling errors, adding key personnel, minor changes to questionnaires, recruiting and changes, and so forth. Other, more substantive changes, especially those that may alter the risk-benefit ratio, may require Full Board review. In all cases, except where noted above regarding subject safety, any changes to any protocol document or procedure must first be approved by NASREC before they can be implemented.

Should you have any questions regarding anything indicated in this letter, please do not hesitate to get in touch with us at the above indicated address.

On behalf of NASREC, we would like to wish you all the success as you carry out your study.

Yours faithfully,

Dr. Mususu Kaonda

VICE CHAIRPERSON
THE UNIVERSITY OF ZAMBIA NATURAL AND APPLIED SCIENCES RESEARCH ETHICS COMMITTEE - IRB

cc: Director, Directorate of Research and Graduate Studies
Assistant Director (Research), Directorate of Research and Graduate Studies
Assistant Registrar (Research), Directorate of Research and Graduate Studies