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# Analysis of Maintenance Practices of Major Underground Production Mobile Equipment: A Case Study of Mega Mine

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***Abstract***
**The objective of any mining organization is to make a profit and sustain the business. For an underground mining operation, production performance largely depends on the availability and utilization of primary equipment used to generate and transport material from underground to surface as well as within the Mine. To ensure the desired output is achieved, mining operations have resorted to setting performance targets for indices such as equipment availability and utilization, meters drilled as well as material moved. Actual performance is tracked and constantly measured against set goals. The performance of Drill Rigs, Loaders and Dump Trucks is key to a mining cycle. Hence, during mining capacity planning and activity scheduling, anticipated major production mobile equipment downtime, both planned and unplanned is considered. To keep maintenance related downtime lower, an effective maintenance regime is essential. By implementing and optimizing maintenance processes, the Mine can reduce costs, improve performance and reliability, thus adding value to the organization. This study therefore aims at identifying major challenges and shortfalls in the maintenance of the major underground equipment at Mega Mine. The investigation is based on a single Underground Mine, Mega Mine (not the real name), and does not take into account benchmarking of activities with other operations. This is because, although activities in various underground mining entities may be similar, the interpretation and calculation of certain terms, factors, parameters, and indices relating to mining activities tend to vary. The main reason for this phenomenon is largely due to different environmental conditions, management approach, lack of publicly available benchmarks and the variation in performance measurement parameters within the industry. An ethnographic study was conducted with the writer being attached to the Mine Maintenance Department during the period of the study. Data was collected through observations, interviews and document review. The most significant finding to emerge from this study is that the Mega Mine Maintenance Department has not conducted a Maintenance Gap Analysis to respond to key maintenance goals to address any maintenance shortfalls. Lack of a formalized maintenance system has created a situation where the Department constantly deals with crises (Reactive to work), prioritizing short-term solutions which result in missed opportunities for long-term equipment reliability and productivity of the maintenance Crews.**

***Keywords*: Maintenance, Planning, Scheduling, Reliability**

## 1. INTRODUCTION

The objective of any mining organization is to make a profit and sustain the business. For an underground mining operation, production performance largely depends on the availability and utilization of primary equipment used to generate and transport material from underground to surface as well as within the Mine. To ensure the desired output is achieved, mining operations have resorted to setting performance targets for indices such as equipment availability and utilization, meters drilled as well as material moved. Actual performance is tracked and continuously measured against set goals. The performance of Drill Rigs, Loaders and Dump Trucks is key to the mining cycle. Hence, during mining capacity planning and activity scheduling, anticipated major production mobile equipment downtime, both planned and unplanned is considered. Nevertheless, during the production process, emphasis tends to shift from the efficient use of resources to meeting set production targets. 'Production tends to take the center stage'. This phenomenon has been triggered by a surge in demand for minerals worldwide which has translated into much higher prices and, with it, much increased miners' profitability. Thus, boosting production volumes has become the industry's top priority. To keep maintenance related downtime low, an effective

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maintenance regime is essential. By implementing and optimizing maintenance processes, the Mine can reduce costs, improve performance and reliability, thus adding value to the organization. Song et al (2015) indicates that there have been more research studies conducted to improve the performance of surface mining operation with many commercial software applications developed than studies carried out to improve the mining process of underground Mines. From their investigation, it is discovered that, in underground Mines, mobile mining equipment is mostly scheduled instinctively, without theoretical support for decision making, conditions which lead to less confidence for miners and less efficient operations. To this effect, they proposed a method known as schedule optimizer for mobile mining equipment which aims at improving the working efficiency and reducing the working time of the underground mine.

This study therefore aims at identifying major challenges and shortfalls in the maintenance of the major underground equipment at Mega Mine. The investigation is based on a single Underground Mine, Mega Mine and does not take into consideration benchmarking of activities with other operations. This is because, though activities in various underground mining entities may be similar, the interpretation and calculation of certain terms, factors, parameters, and indices relating to mining activities tend to vary. The main reason for this phenomenon is largely due to different environmental conditions, management approach, lack of publicly available benchmarks and the variation in performance measurement parameters within the mining industry. Some of the major Key Performance Indicators are discussed in this detail to provide clarity to those that may not be familiar with such indices or terminologies.

## 2. KEY PERFORMANCE INDICATORS (KPI)

To ensure the desired optimum equipment performance, the Maintenance Section sets equipment performance targets for indices such as:

### 2.1 Availability

This is the amount of time a machine is available for operation and expressed as a percentage of scheduled time. This time may also be referred to as 'Up Time". According to Dhillon (2008), availability is termed as the probability that a piece of equipment is functioning satisfactorily at a specified time, when used according to specified conditions, where the total time includes operating time, logistical time, active repair time, and administrative time. Hence, availability is calculated as follows:

$$A = \frac{SSH - (MH + BD)\ X\ 100}{SSH}$$

where:

A = Equipment Availability

SH = Scheduled Hours

MH = Maintenance Hours

BH = Breakdown Hours

Scheduled hours imply the planned operating time assigned to a machine to ensure the set output is achieved. Thus, this time is set in line with production budgets (mine plan). Scheduled time excludes blast re-entry time, meal breaks, toolbox talks, shift changeover and management time. However, different management may interpret these exclusions differently to suit their environment.

When scheduling this time, it is important to take note of planned maintenance, equipment audits and pre-start inspections, refueling and components replacement time.

Maintenance hours denote the time a machine is out of operation due to planned/preventive maintenance, also known as planned downtime. This requires accurate forecasting to ensure all maintenance activity time such as planned audits and major component replacement is considered. On the other hand, breakdown hours represent the time that the machine is out of operation due to a machine breakdown, also referred to as unplanned downtime.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 04, April-2025

2.2 Utilization

In this document, utilization refers to the amount of time a machine is available for operation. In other words, utilization is the time a machine is in active operation of the available hours. It may also be termed as operational availability and calculated as follows:

$$U = \frac{SH-(MH+BH+IH)\ X\ 100}{SH}$$

Where:

U = Equipment Utilization

SH = Scheduled Hours

HM = Maintenance Hours

BD = Breakdown Hours

IH = Idle Hours

Note that idle hours represent the time when a piece of equipment is ready for use but not used due to standby or operational delays.

Additionally, Temeng (2012) states that other factors that may affect the utilization of equipment include competency of mine personnel, efficiency of the Mine Plan and support equipment commitment.

2.3 Mean Time To Repair (MTTR)

Esmaeili (2016) asserts Mean Time to Repair as the average time required to repair a piece of equipment and is expressed as the total repair time divided by the total number of repairs.

In elementary terms, Mean Time To Repair is expressed as the time taken to repair a machine to the frequency of breakdowns and calculated in hours as.

$$\text{MTTR} = \frac{\Sigma\,(\text{Breakdown Time})}{\#\,\text{Breakdowns}}$$

2.4 Mean Time Before Failure (MTBF)

Esmaeili (2016) expresses Mean Time Between Failures (MTBF) as the mean time of the failure distribution of a machine or component and for a constant failure rate, it is expressed as the total operating time divided by the total number of repairs.

$$\text{MTBF} = \frac{\text{Operating Hours}}{\#\,\text{Failures}} = \frac{1}{\lambda}$$

Mean Time Before Failure is therefore expressed as the total breakdown time in hours to the total number of failures.

## 3. UNDERGROUND PRIMARY EQUIPMENT

The major production machines in an underground mine consist of Drill Rigs, which fall into Development, Long hole or Production and Support Drill Rigs, Loaders, and Dump Trucks. In underground mining, these three machines form part of the major cost drivers of the production process. As such, the Mine Management always looks forward to the efficient use of this equipment. Justifying this phenomenon, Bullock (2011) implies that the efficiency of a modern mining system depends heavily on the productivity and availability of the equipment used to extract the material from underground. Thus, underground production equipment availability and utilization play an important role in mining productivity.

The study provides visual aid for the equipment under discussion to offer a powerful way of conveying information and concepts, making the study more inclusive and dynamic, especially to those that may not have full knowledge of the equipment.

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Vol. 14 Issue 04, April-2025

3.1 Underground Drill Rig

In general, an Underground Drill Rig is a machine used for making holes in the rock. Nevertheless, this machine comes in various forms and is constructed according to the duty required. They are either designed for production drilling, ground support, exploration drilling or technical drilling and they are either propelled by gas, water, or electrical power. The majority of Drill Rigs used underground use diesel engines for tramming the machine and electrical power for drilling and support operations. A Drill Rig is an important machine in ore generation and considered the frontline machine in the underground production process. With the advancement of technology and the quest for people's safety, remote-controlled Drill Rigs are now available on the market and used underground.


Underground Drill Rig

The major sections of a Drill Rig as seen from Figure 1 include:

i. Drilling Lights – the machine is fitted with clear drilling lights on the canopy.
ii. Engine – the engine provides power for tramming the machine.
iii. Axle – carried the tires and houses the differential as well as the brake assembly. Other designs may have wheels driven by individual hydraulic motors.
iv. Operator's cabin – carries operational controls and monitoring gauges for the operator and shelters the operator.
v. Hydraulic Jack – used for securing the machine while drilling.
vi. Boom – carries the drilling mechanism of the machine.
vii. Feed Beam – carries and provides sliding platform for the drifter.
viii. Hydraulic hoses – supply hydraulic fluid to all hydraulic components of the machine.
ix. Drill Rod – carries the drill bit which penetrates the ground.
x. Drifter – provides rotary motion to the drill rod.
xi. Tramming lights – provide light when moving the machine.
xii. Feed Carrier – the feed carrier holds the feed beam in place, and it is attached to the turning device.
xiii. Turning Device – the turning is a cylindrical unit which provides rotation motion to the feed beam.
xiv. Main Hydraulic Pump – the main hydraulic pump pumps oil to all hydraulic components of the machine.
xv. Main Electric Motor – the main electric motor rotates the main hydraulic motor. The motor is supplied with an external source of electric power through a flexible cable rolled on a cable reel of the Drill Rig.
xvi. Front Centralizer – the front centralizer guides the drill rod while drilling.
xvii. Dowel – this is the front part of the feed beam which is usually pressed against the rock during drilling operation. To avoid shock loading of the boom assembly, the dowel plate is lined with rubber.
xviii. Mid Centralizer – prevents the drill rod from excess vibrating.

The electric motor mounted on the machine rotates the main hydraulic motor which provides power to working parts of the machine such as cylinders and hydraulic controls.

3.2 Underground Dump Truck

An Underground Dump Truck is a special machine used for loading, hauling, and damping loads in and out of the Mine. The machine is built to withstand hostile underground conditions. It is powered by a high-power engine, has a good loading capacity and great traction. This machine attributes are purposed for underground conditions. Additionally, the narrow size of the machine makes it ideal for mining operations and on the other hand, the operator cabin is built to protect the operator from various kinds of accidents such as rock fall and rolling of the machine. The operator cabin is of the ‘Roll Over Protection Structure (ROPS) and ‘Fall Over Protection Structure (FOPS)’.


Figure 2: Underground Mine Dump Truck

Though the Underground Dump Trucks may differ in size, the major features are similar. Figure 2 shows the main features of the Mine Dump Truck:

i. Operator Cabin – houses all the machine operating controls such as meters and gauges, Joystick/steering ring, foot control peddles and switches.
ii. Axle – carried the tires and houses the differential as well as the brake assembly.
iii. Dump Cylinder – depending on the vehicle design, a Dump Truck may be fitted with a single or double dump cylinder. The dump cylinder is used for lifting and retracting the dump box, also known as the bowl.
iv. Dump Box – this is the main body of a Dump Truck used for carrying material. Some dump boxes have liners to protect the body, while others have no liners.
v. Hydraulic Tank – stores hydraulic oil for the machine.
vi. Transmission – provides power to axles through drive shafts.
vii. Engine – the engine is the source of power for the machine.
viii. Center Section – the machine articulation section.
ix. Rear Frame – carries the rear part of the machine including the dump box.
x. Drive Shaft – transmits power (rotational) to the axles.

Underground Mine Trucks come in various sizes depending on the tunnel size, mine production capacity and the physical size of the Mine. These Trucks are built to operate in harsh environmental conditions.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 04, April-2025

3.3 Underground Loader

An underground mining Loader is a machine mostly used for loading ore and rock waste into Dump Trucks. Other secondary duties may include filling uneven road surfaces and cleaning mining sites.

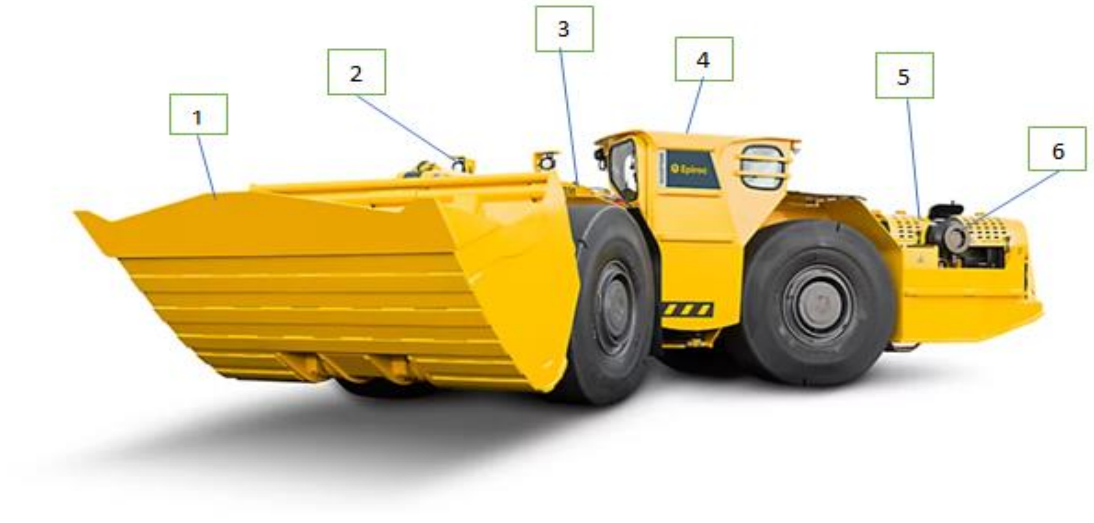


*Figure 3: Underground Mine Loader*

As seen from Figure 3, the major features of a mining Loader include:

i. Bucket – the main use of the Loader bucket is to load material into Dump Trucks. The Loader bucket is engineered with the toughest abrasion-resistant steel in high-wear areas to reduce repair times and improve structural strength. Ground Engagement Tool (GET) is usually inserted on the bucket lip to extend the bucket life.
ii. Tramming Lights – a Loader is fitted with high lux lights both in front and at the rear for easy visibility.
iii. H-Frame – the Loader H-Frame a metallic structure in 'H' form to which the Loader bucket is attached. The upward, downward and tilt motion of the bucket are initiated through hydraulic cylinders attached to the Loader body and the H-Frame.
iv. Operator Cabin – the Cabin houses all the machine operating controls such as meters and gauges, Joystick/steering ring, foot control peddles and switches. The operator Cabin is of the 'Roll Over Protection Structure (ROPS) and 'Fall Over Protection Structure (FOPS)'.
v. Engine – the engine is the main source of power for a mining Loader. It delivers power to the gearbox and finally to the axles through drive shafts. The engine is either liquid or air cooled.
vi. Air Filter – the air filter prevents dust and other foreign materials from entering the engine combustion system. The air filter also makes possible a good air fuel mixture to support engine performance.

Underground Loaders are manufactured in numerous sizes depending on the tunnel size, mine production capacity, and the physical size of the Mine. The Loader is constructed to work in harsh environmental conditions.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 04, April-2025

## 4. RELATED WORK

An organization's profitability largely depends on the efficient use of production resources. As such, mining operations develop Mine Plans aimed at establishing and developing a cost-effective solution for the extraction of mined minerals at optimal quality and quantities using various mining resources. In line with this thought process, Song et al (2015) claims that, to improve the profit and recover the investment of a Mine, it is important to optimize the mining process and keep the process in an optimal/near-optimal manner to obtain the target of the overall Mine Plan.

With the aim of improving operational performance for underground mining, studies have been conducted to optimize the Dump Truck hauling cycle time. Weintraub et al (1987), carried out a study at Chuquicamata Mine in Chile and proposed a linear programming-based heuristic approach to multiple Trucks with various capacities to minimize queuing time at loading points. The use of this method at the same Mine resulted in an 8% increase in productivity. Though Improving the Dump Truck cycle time is significant to a mining operation, other efficiency inhibiting factors must be pursued to get ultimate process efficiency. Further, Arputharaj (2015) highlights some of the important aspects required to meet desired production budgets. He explains that producing projected level minerals in a stipulated period is mostly dependent upon proper utilization of equipment and their consequences.

Sankha and Dey (2015) acknowledge the observation made by Arputharaj (2015) by stating that, the improvement of production rates and equipment availability are very case sensitive in any kind of industry. They further warn that required capacities are controlled by various influencing factors and concluded that the improvement of Overall Equipment Performance (OEP) is essential and could be improved by proper measurement of equipment availability and its capacity utilization factors.

Among the various definitions of performance measurements, OEP may be defined as the ratio of produced output to the utilized resources. Produced output can be taken in many ways based on the requirement and can be expressed on a daily, monthly, or annual basis. During equipment performance analysis, these values are usually taken as an average value for a desired period.

Kansake and Suglo (2011) carried out a study at Konjole Mine Limited in Ghana to determine the cause of the numerous Drill Rig breakdowns at the mine. From their study, it is noted that the availability and utilization of mining equipment such as Drill Rigs and Dump Trucks is critical in the mining production cycle. They indicate that to ensure reliability and efficiency, the performance of production equipment is regularly measured using parameters such as availability and utilization. From their evaluation, it is reviewed that to improve productivity, it is imperative to optimize availability and utilization of the equipment assigned to production. In the quest to determine these failure causes, the duo also claim that, though much research has been done on the selection of equipment, little attention has been given to the measurement of equipment effectiveness. This observation is also echoed by Bullock (2011) who makes it clear that the efficiency of a modern mining system depends heavily on the productivity and availability of the equipment used to extract the material. From this narrative, it is therefore important to identify and understand issues which affect these factors of production.

## 5. COMMON MAINTENANCE TERMINOLOGIES

Terms that could be beyond common language to some readers have been defined in this Section. This is because different studies present words or expressions that may have a precise meaning in a specified field of research that may not be easily understood by people not in that field, such words, or expressions, therefore, need explaining to the reader to ensure clarity.

i. Maintenance – A combination of all technical, administrative, and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function.
ii. Maintenance Plan - Structured set of tasks that include the activities, procedures, resources, and the time required to carry out maintenance.
iii. Availability (Performance) - Ability of an item to be in a state to perform a required function under given conditions at a given instant of time or during a given time interval, assuming that the required external resources are provided.
iv. Reliability - Ability of an item to perform a required function under given conditions for a given time interval.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 04, April-2025

v. Maintainability - Ability of an item under given conditions of use, to be retained in, or restored to, a state in which it can perform a required function, when maintenance is performed under given conditions and using stated procedures and resources.
vi. Failure - Termination of the ability of an item to perform a required function.
vii. Preventive Maintenance - Maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an item.
viii. Condition Based Maintenance - Preventive maintenance based on performance and/or parameter monitoring and the subsequent actions.
ix. Predictive Maintenance - Condition based maintenance carried out following a forecast derived from the analysis and evaluation of significant parameters of the degradation of the item.
x. Corrective Maintenance - Maintenance carried out after fault recognition and intended to put an item into a state in which it can perform the required function.
xi. Deferred Maintenance - Corrective maintenance which is not immediately carried out after fault detection but is delayed in accordance with given maintenance rules.
xii. Operator Maintenance - Maintenance carried out by a user or operator.
xiii. Inspection - Check for conformity by measuring, observing, testing, or gauging the relevant characteristics of an item.
xiv. Repair - Physical action taken to restore the required function of the faulty item. (EN 13 306, 2000)

## 6. DATA COLLECTION

Being an ethnographic study, all the data was collected by the writers. This involved the use of different research techniques which include observations, taking field notes, informal conversations, interviews, document analysis, surveys and working with the Mega Mine maintenance team on underground mobile equipment.

### 6.1 Equipment Performance

The staring point was the review of various documentation relating to equipment statistics and performance. Table 1 shows the number of Loaders utilized at Mine from January 2022 to December 2022.

Table 1: Loaders

| Loaders | Fleet No. | Make | Duty |
|---|---|---|---|
| **ST1030** | 2 | EPIROC | Loading |
| **ST 1030** | 3 | EPIROC | Loading |
| **ST1030** | 4 | EPIROC | Loading |
| **ST1030** | 5 | EPIROC | Loading |
| **ST 1030** | 6 | EPIROC | Loading |
| **ST 1030** | 7 | EPIROC | Loading |
| **ST 1030** | 8 | EPIROC | Loading |
| **SANDVIK LH 514** | 514 | SANDVIK | Loading |

Most of the Loaders used are 10 Tone Epiroc machines. There is only one Sandvik 14 Ton LH514 Loader at the Mine. Table 2 gives a list of Dump Trucks used at Mega Mine.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 04, April-2025

Table 2: Dump Trucks

| Dump Trucks | Fleet No. | Make | Duty |
|---|---|---|---|
| **MT436B** | 1 | EPIROC | Hauling |
| **MT431B** | 2 | EPIROC | Hauling |
| **MT431B** | 3 | EPIROC | Hauling |
| **MT436B** | 4 | EPIROC | Hauling |
| **MT436B** | 5 | EPIROC | Hauling |
| **MT436B** | 6 | EPIROC | Hauling |
| **MT436B** | 7 | EPIROC | Hauling |
| **MT436B** | 8 | EPIROC | Hauling |
| **MT436B** | 9 | EPIROC | Hauling |

All Dump Trucks are Epiroc machines comprising two MT431B and seven MT436B models. The Trucks ferry material from underground to surface.

Table 3 shows all models of Drill Rigs used at the Mine for various operations.

Table 3: Drill Rigs

| Drill Rigs | Fleet No. | Make | Duty |
|---|---|---|---|
| **S1D Boomer** | 1 | EPIROC | Face Drilling |
| **S1D Boomer** | 2 | EPIROC | Face Drilling |
| **S1D Boomer** | 3 | EPIROC | Face Drilling |
| **S1D Boomer** | 4 | EPIROC | Face Drilling |
| **S1D Boomer** | 5 | EPIROC | Face Drilling |
| **S1D Boomer** | 6 | EPIROC | Face Drilling |
| **Support Boltec** | 1 | EPIROC | Support |
| **Support Boltec** | 2 | EPIROC | Support |
| **Support Boltec** | 3 | EPIROC | Support |
| **Support Boltec** | 4 | EPIROC | Support |
| **Support Boltec** | 5 | EPIROC | Support |
| **Support Troidon** | 2 | RESEMIN | Support |
| **Support/Face Troidon** | 3 | RESEMIN | Support And Face Drilling |
| **Long Hole Raptor** | 1 | RESEMIN | Production |
| **Long Hole Simba** | 1 | EPIROC | Production |
| **Long Hole Simba** | 2 | EPIROC | Production |
| **Long Hole Simba** | 3 | EPIROC | Production |

As seen from Table 3, Drill Rigs operated at the Mine range from face development drilling, production drilling to final support drilling and support installation. Exploration Drill Rigs have not been considered in the study as they are operated and maintained by a contractor.
Loader availability figures from January 2022 to December 2022 were collected and displayed in figure 5.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 04, April-2025

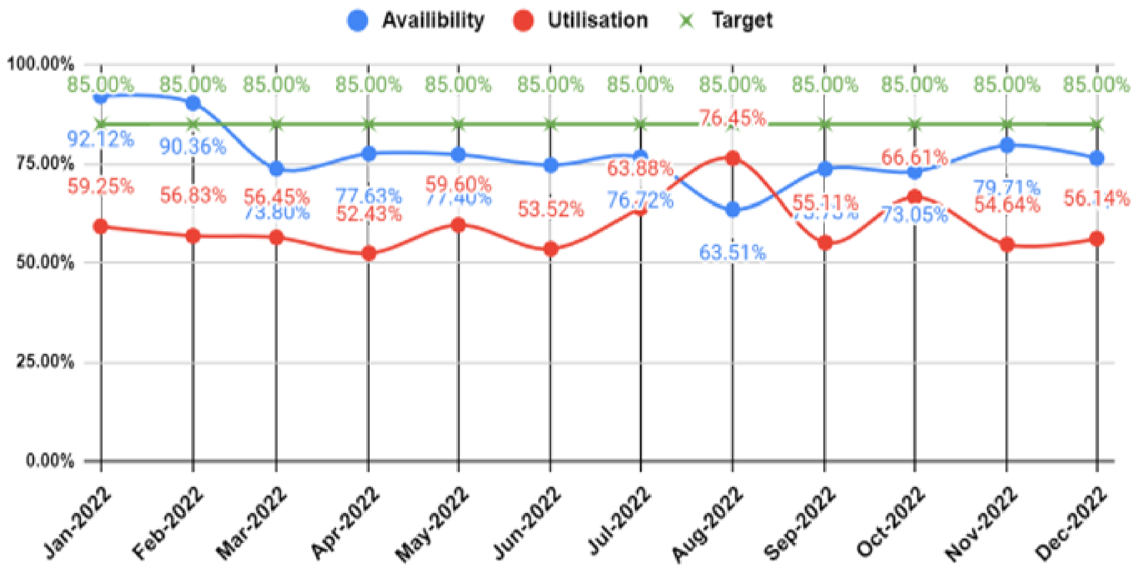


Fig. 5: Loader Performance

The Target availability for Loaders is set at 85%. Nevertheless, this score was only achieved twice in January and February. From document review, it is indicated that the major contributing factor to the frequent and longer machine downtime is the delay in the procurement of replacement parts by the Supply Department and in country logistics.

Three months were picked at random to determine the most frequent failure modes on Loaders. To achieve this, a pareto analysis of system failure frequency was conducted, and the results are shown in Fig. 6.

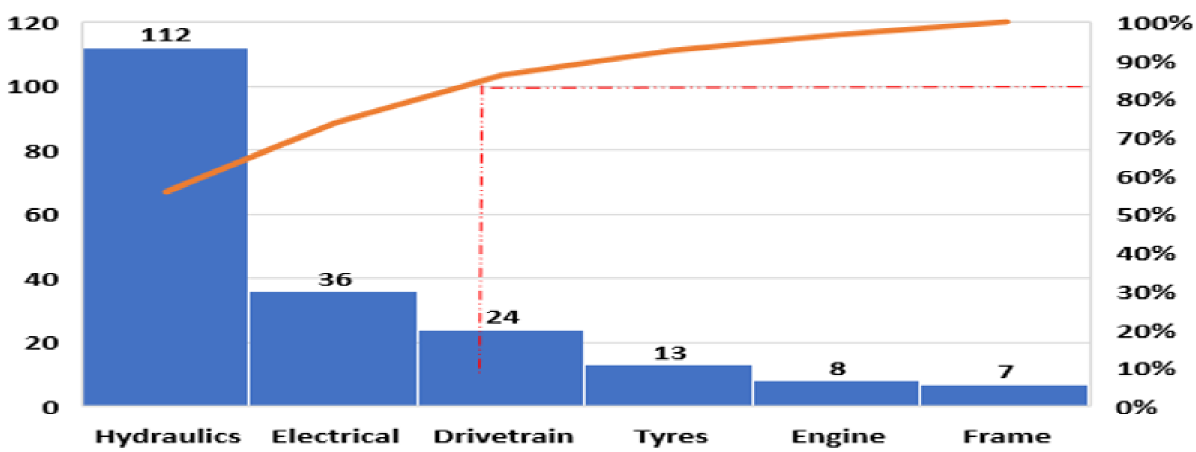


Fig. 6: Loader System Failure Frequency

The identification of the most frequent failure modes narrows the area of investigation and allows for attention to be directed at a few critical areas of concern.

Though the frequency of frame failures is low, the impact in terms of downtime is significant and failures are mostly associated with the H-frame assembly.

The performance of Dump Trucks was satisfactory in relation to the set availability target of 85%. The budget was only missed in June 2022 when a score of 81.75% was registered. This can be seen from Fig. 7.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 04, April-2025

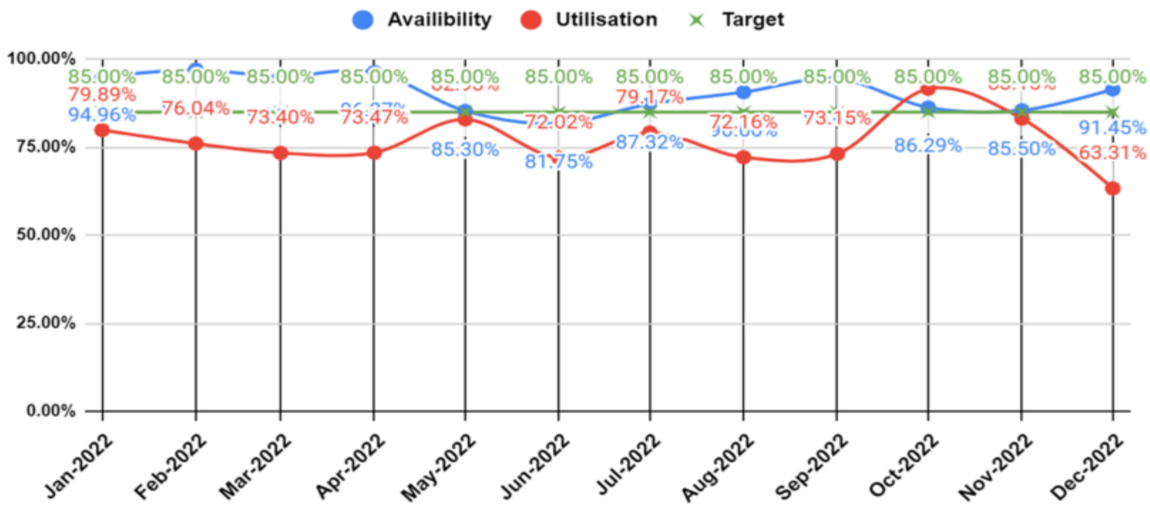


Fig. 7: Dump Truck Performance

One reason assumed for the satisfactory performance of Dump Trucks is that most of them were new, Nonetheless, some breakdowns were recorded during the period under review. To investigate the extent of these breakdowns, a pareto analysis of failure frequency was conducted as shown in Fig. 8.

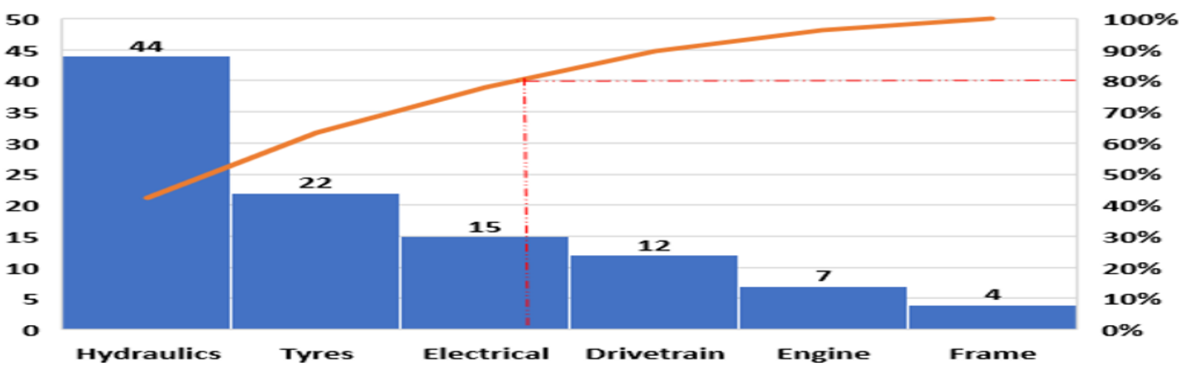


Fig. 8: Dump Truck System Failure Frequency

The greater number of downtime events is from hydraulic systems, tyres and partially electrical. The main problem with hydraulic systems is hose failure. From the data collected from the Maintenance office, the side cut is the most prominent cause of tyer failure.

There were isolated electrical failure modes which include harness and machine controls. Nevertheless, these are not significant as their impact on downtime is insignificant.

The availability of Drill Rigs was equally recorded, and the results shown in Fig. 9.

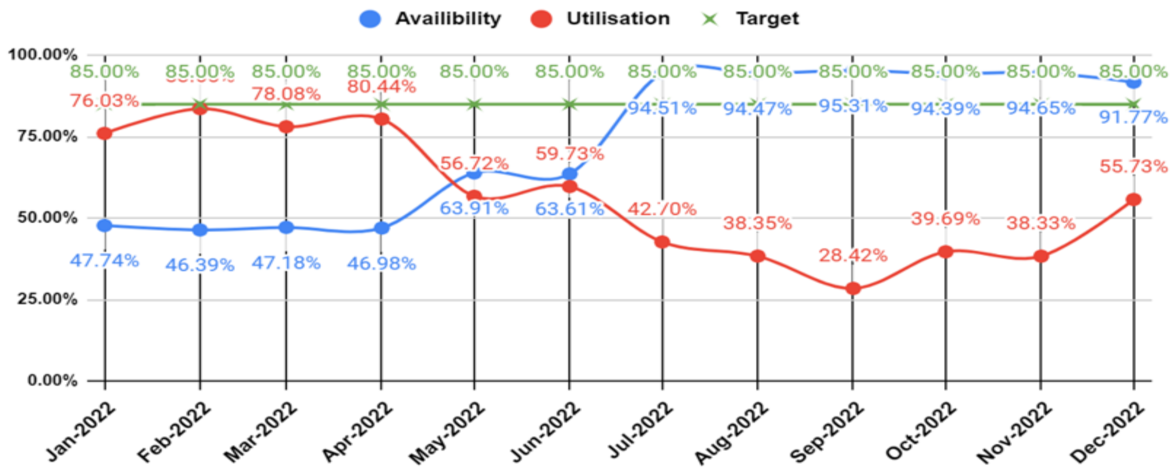


Fig. 9: Drill Rig Performance

Drill Rigs are key in the underground production process, poor Drill Rig availability causes a significant lag in the whole production process. The availability of Drill Rigs was lower during the first half of the year as seen from Fig. 9. However, the availability improved significantly during the second half of the year, trending above budget.
There were several breakdowns which led to the lower-than-expected availability of Drill Rigs during the period under review. To identify the most frequent downtime causes, a pareto analysis of failure frequency was developed as shown from Fig. 10.

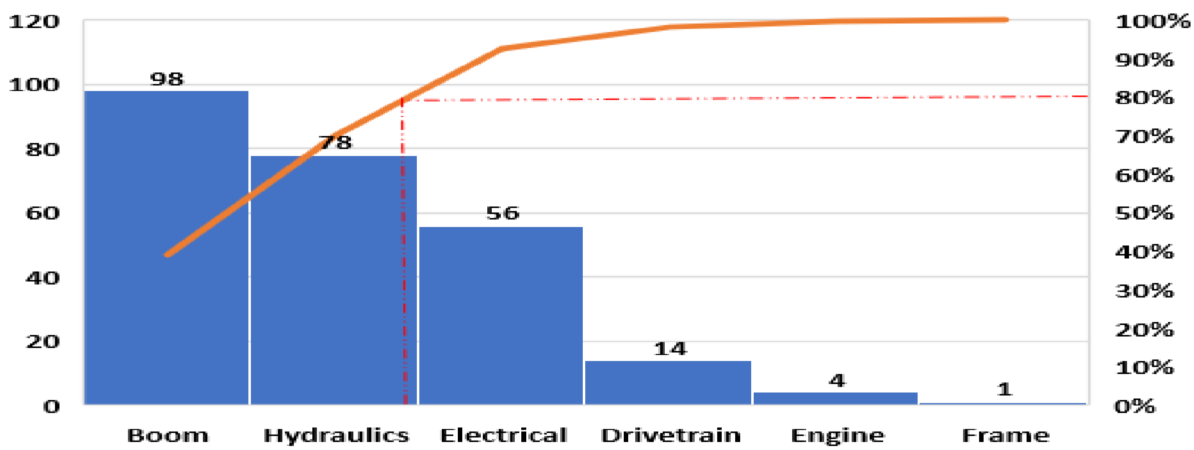


Fig. 10: Drill Rig System Failure Frequency

The highest frequency of failure relates to the boom. At the time of the study, it was noted that most of the Drill Rig Operators did not have adequate skills. However, Mega Mine had made training arrangements with Epiroc the Machine OEM.
Equipment damage constituted a greater number of the boom section failures and as indicated; this was mainly due to poor machine operation as the operators did not have sufficient skills to carry out certain operations.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 04, April-2025

6.2 Planned Maintenance Methodology

The maintenance philosophy adopted at Mega Mine was reviewed, and it was found out that the type of maintenance varied depending on the type of machine and duty as seen from table 4.

Table 4: Maintenance Type and Frequency

| Machine Type | Frequency | Activity | Comments |
|---|---|---|---|
| Loaders and Dump Trucks | Daily Inspection | Primary Air filters are inspected and replaced if found to be clogged. Oil level, general system health and function checks are conducted. | Any faults requiring attention are resolved and those that can wait are placed on backlog. |
| | 250 Hours | Engine oil including filters is changed. Oil from the differentials, gearbox and hydraulic system is checked and topped up if low. General inspection of the machine is carried out. | Any faults requiring attention are resolved and those that can wait are placed on backlog. |
| | 500 Hours | All filters are replaced during this service. Engine oil is replaced. General inspection of the machine is carried out. | Any faults requiring attention are resolved and those that can wait are placed on backlog. |
| | 1000 Hours | All filters are replaced. Oil in all compartments is replaced. General inspection of the machine is carried out. | Any faults requiring attention are resolved and those that can wait are placed on backlog. |
| | | | |
| Drill Rigs | Daily Inspection | Oil level from all compartments is checked and topped up if low. | Any faults requiring attention are resolved and those that can wait are placed on backlog. |
| | 250 Hours | Engine oil and filters is replaced. Oil level of other compartments is checked. General checks and systems functionality checked. | Any faults requiring attention are resolved and those that can wait are placed on backlog. |
| | 500 Hours (Engine and percussion) | Replace all filters Replace engine oil. General system health and function checked. | Any faults requiring attention are resolved and those that can wait are placed on backlog. |
| | 1000 Hours (Engine and Percussion) | All filters are replaced. Oil in all compartments is replaced. General inspection of the machine is carried out. | Any faults requiring attention are resolved and those that can wait are placed on backlog. |

To carry out these tasks, the Maintenance Planner allocates manpower and time according to the maintenance type as seen from Table 5. However, there is no written philosophy to support the idea. On the other hand, there is no clear and consistent maintenance schedule, scheduling is random.

Table 5: Labor Allocation and Maintenance Duration

| Machine Type | Service Type | Duration | No. of Technicians | Comments |
|---|---|---|---|---|
| All machines | Daily Service | 0.5 Hours | 1 | If greasing is required, or any other faults are found, maintenance may go beyond 0.5 hours. |
| Loaders and Dump Trucks | 250 Hours | 3.0 Hours | 2 | If greasing is required, or any other faults are found, maintenance may go beyond 3 hours. |
| | 500 Hours | 4.0 Hours | 2 | If greasing is required, or any other faults are found, maintenance may go beyond 4 hours. |
| | 1000 Hours | 6.0 Hours | 2 | If greasing is required, or any other faults are found, maintenance may go beyond 6 hours. |
| | | | | |
| Drill Rigs | 250 Hours | 4.0 Hours | 2 | Includes securing of hoses, spirals, and replacement of worn-out hoses. |
| | 500 Hours | 5.0 Hours | 2 | Includes securing of hoses, spirals, and replacement of worn-out hoses. |
| | 1000 Hours | 7.0 Hours | 2 | Includes securing of hoses, spirals, and replacement of worn-out hoses. |

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 04, April-2025

The planning and scheduling of these tasks is done from the Engineering Planning Office with the input of Foremen and Superintendents. However, there is no fixed schedule for periodic maintenance to give enough time to the operations department to go through the schedule and raise any concerns if any. From site observations, there was a high level of cooperation from the mining department to hand in machines for maintenance when required.

From document review, it is noted that during the first half of the year, some machines were standing awaiting replacement parts. The mine procures over 90% of the maintenance and major components from Epiroc in Tanzania. It was however noted that most of the time, Epiroc Tanzania did not have stock at hand and had to source through Sweden. This situation results in waiting for certain parts for as long as six months.

### 6.3 Equipment Maintenance Approach and Practices

Maintenance of the Mobile Equipment at Mega Mine starts from the time a machine is commissioned, new or refurbished. From commissioning, planned maintenance commences there is no formal strategy or plan.

#### 6.3.1 Machine Commissioning

Commissioning of a machine is a risk-based process of ensuring that all systems and components of the machine comply with the Mine requirements which are always stated in the purchase document. Commissioning involves verification of design, testing of systems, physical operation of the machine and ensuring that all the necessary documentation such as maintenance and operator manuals are available. This task is carried out by a representative from the equipment supplier who, after completing all inspections, prepares a commissioning certificate which is handed over to the Mega Mine Maintenance Manager.

In summary, commissioning is carried out to ensure the purchased or rebuilt machine is fully functional as per the Mine requirements. Additionally, to ensure the safety of both Operators and Maintenance personnel, training is conducted by the OEM. Commissioning acts as a warranty cover as all equipment premature failures can be justified for the purpose of a warranty claim with reference to the commissioning certificate. The process of commissioning equipment also allows management to develop appropriate risk mitigations that ensure the machine is safe for both personnel and the environment. This process is, however, managed correctly by the Mega Mine Maintenance Department.

#### 6.3.2 Routine Maintenance

The Mine Maintenance Team carries out maintenance and inspection of equipment as and when required by the maintenance personnel. Table 6 shows the activities carried out during Daily Inspection of Dump Trucks and Loaders.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 04, April-2025

Table 6: Dump Truck and Loader Daily Inspection

| Machine Type | Model | Complexity | Service Scope | Responsible | Duration |
|---|---|---|---|---|---|
| Loader | **Epiroc** Scoop Tram ST1030<br><br>**Sandvik** LH514 | Electromechanical control and radio remote operation option. Up to 5 onboard ECUs using CAN bus system for machine parameter monitoring and control. | Static: Machine locked out and thoroughly cleaned. All points greased, inspected for leaks and damages.<br>Active 01: Machine diesel engine switched on and all controls, lights, brakes, and all safety features tested. | 01 x Heavy Equipment Mechanic | 30 to 45 Minutes |
| Dump Truck | **Epiroc** Mine Truck MT431B and MT436B | The Truck comes with unique features including Jacob's engine brake, automatic engine over-speed protection, electric transmission shift control and converter lockups. The truck is designed to facilitate fast and efficient service. The machine has no complicated electronic or electromechanics systems. | Static: Machine locked out and thoroughly cleaned. All points greased, inspected for leaks and damages.<br>Active 01: Machine diesel engine switched on and all controls, lights, brakes, and all safety features tested. | 01 x Heavy Equipment Mechanic | 30 to 45 Minutes |

The underground mining operations are split into two; Dayshift (06:00 hours to 18:00 hours) and Nightshift (18:00 hours to 06:00 hours), therefore, the machines are inspected during the start of each shift. Any faults identified during inspection are corrected, but if the fault is not severe, the repair is scheduled to a later date. This date, however, depends on the availability of manpower and parts if required.
Other than the Daily Inspection, the Maintenance Team carries out Planned Maintenance at specified intervals as illustrated in Table 7.

Table 7: Dump Truck and Loader Time Based Planned Maintenance

<table>
<tr><th>Machine Type</th><th>Model</th><th>Service Scope</th><th>Responsible</th><th colspan="2">Duration (hours)</th></tr>
<tr><td rowspan="6">Loader</td><td rowspan="6">Epiroc Scoop Tram ST1030<br><br>Sandvik LH514</td><td rowspan="6">• Thorough washing and cleaning<br>• Pre-service testing<br>• Calendar and usage-based Service<br>• Corrective repairs of priority concerns identified during pre-service inspections</td><td rowspan="6">• 01 x Certified Heavy equipment Mechanic<br>• 01 Uncertified Heavy equipment Mechanic<br>• 01 Certified Auto-Electrician</td><td>Schedule</td><td>Engine</td></tr>
<tr><td>Cleaning and Testing</td><td>1.0</td></tr>
<tr><td>Weekly</td><td>1.5</td></tr>
<tr><td>250hrs</td><td>2.0</td></tr>
<tr><td>500hrs</td><td>3.0</td></tr>
<tr><td>1000hrs</td><td>4.0</td></tr>
<tr><td rowspan="6">Dump Truck</td><td rowspan="6">Epiroc Mine Truck MT431B and MT436B</td><td rowspan="6">• Thorough washing and cleaning<br>• Pre-service testing<br>• Calendar and usage-based Service<br>• Corrective repairs of priority concerns identified during pre-service inspections</td><td rowspan="6">• 01 x Certified Heavy equipment Mechanic<br>• 01 x Uncertified Heavy equipment Mechanics<br>• 01 Certified Auto-Electrician</td><td>Schedule</td><td>Engine</td></tr>
<tr><td>Cleaning and Testing</td><td>1.0</td></tr>
<tr><td>Weekly</td><td>1.5</td></tr>
<tr><td>250hrs</td><td>2.0</td></tr>
<tr><td>500hrs</td><td>3.0</td></tr>
<tr><td>1000hrs</td><td>4.0</td></tr>
</table>

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 04, April-2025

The Planning Section handles both Planning and Scheduling activities. When a machine is required for maintenance, the Planning Section issues a request to the mining management at least a day before the maintenance day. The schedule is submitted early to allow for any amendments to the plan. This schedule shows the type of maintenance, date of maintenance and the machine identification number.

During maintenance of each machine, a maintenance checklist is issued to the Foreman who gives it to the responsible Technician. This checklist is followed during planned maintenance and once the task is completed, the Technician signs the checklist and hands it over to the Planning Office. Table 8 shows the activities carried out during the Daily Inspection of Drill Rigs.

Table 8: Drill Rigs Daily Inspection

| **Machine Type** | **Model** | **Complexity** | **Service Scope** | **Responsible** | **Duration** |
|---|---|---|---|---|---|
| Support Drill Rig | **Epiroc** Boltec S | Highly electronic (RCS Version 5), complex boom and feed complete with carousel and welded mesh handling arm. It has both automatic and manual operating mode with two drifters for drilling and support. | Static: Machine locked out and thoroughly cleaned. All points greased, inspected for leaks and damages. Active 01: Machine diesel engine switched on and all controls, lights, brakes, and all safety features tested. Active 02: Machine plugged into mains power supply, tested without drilling and when drilling. All adjustments and minor faults fixed. | 01 x Heavy Equipment Mechanic<br><br>01 Certified power and Auto-Electrician | 30 to 60 Minutes |
| Long Hole Drill Rig *(Also known as Production Drill)* | **Epiroc** Simba 7D and Simba 7C | Highly electronic (RCS Version 5), complex boom and feed complete with drill rod magazine and has both automatic and manual operation mode | Static: Machine locked out and thoroughly cleaned. All points greased, inspected for leaks and damages. Active 01: Machine diesel engine switched on and all controls, lights, brakes, and all safety features tested. Active 02: Machine plugged into mains power supply, tested without drilling and when drilling. All adjustments and minor faults fixed. | 01 x Heavy Equipment Mechanic<br><br>01 Certified power and Auto-Electrician | 30 to 60 Minutes |
| | **Resemin** Raptor 55 2R | Electro-Mechanical control Single boom complete with drill rod magazine. manual operation mode | Static: Machine locked out and thoroughly cleaned. All points greased, inspected for leaks and damages. Active 01: Machine diesel engine switched on and all controls, lights, brakes, and all safety features tested. Active 02: Machine plugged into mains power supply, tested without drilling and when drilling. All adjustments and minor faults fixed. | 01 x Heavy Equipment Mechanic<br><br>01 Certified power and Auto-Electrician | 30 to 60 Minutes |
| Face Drill Rig (*Also known as Tunnelling or Development Drill)* | **Epiroc** Boomer S1D | Machine equipped with RCS. Has Single boom, Solid feed beam equipped with extension drilling steel support clamp. | Static: Machine locked out and thoroughly cleaned. All points greased, inspected for leaks and damages. Active 01: Machine diesel engine switched on and all controls, lights, brakes, and all safety features tested. Active 02: Machine plugged into mains power supply, tested without drilling and when drilling. All adjustments and minor faults fixed | 01 x Heavy Equipment Mechanic<br><br>01 Certified power and Auto-Electrician | 30 to 45 Minutes |
| | **Resemin** Troidon 55-XP | Manual control Single boom, Split feed beam machine capable of manual rock bolting if used by skilled operator. | Static: Machine locked out and thoroughly cleaned. All points greased, inspected for leaks and damages. Active 01: Machine diesel engine switched on and all controls, lights, brakes, and all safety features tested. Active 02: Machine plugged into mains power, tested without drilling and when drilling. All adjustments and minor faults fixed | 01 x Heavy Equipment Mechanic<br><br>01 Certified power and Auto-Electrician | 30 to 45 Minutes |

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 04, April-2025

Like Loaders and Trucks, the Daily Inspection is conducted at the end of each shift by maintenance personnel. At the same time, the operator goes through the machine to check for any defects or unusual observations and reports to the duty Technician. Table 9 specifies the Time-Based Planned Maintenance for Drill Rigs at the Mine.

Table 9: Time Based Drill Rigs Planned Maintenance

| Machine Type | Model | Service Scope | Responsible | Duration (hours) | | | |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Support and Production Drill Rigs | Boltec S/ Simba 7C / Raptor 55 2R | • Thorough washing and cleaning<br>• Pre-service testing<br>• Calendar and usage-based Service<br>• Corrective repairs of priority concerns identified during pre-service inspections | • 02 x Certified Heavy equipment Mechanics<br>• 01 Uncertified Heavy equipment Mechanic<br>• 01 Certified power and Auto-Electrician | ***Schedule*** | ***Engine*** | ***Perc*** | ***PP*** |
| | | | | Cleaning & Testing | 1.5 | | |
| | | | | Weekly | 1.0 | 1.0 | 2.0 |
| | | | | 250hrs | 1.5 | 1.5 | 2.0 |
| | | | | 500hrs | 1.5 | 1.5 | 2.0 |
| | | | | 1000hrs | 2.0 | 2.0 | 2.0 |
| | | | | 2000hrs | 2.0 | 2.0 | 2.5 |
| Face Drill Rigs. | Boomer SD1/ Troidon 55-XP | • Thorough washing and cleaning<br>• Pre-service testing<br>• Calendar and usage-based Service<br>• Corrective repairs of priority concerns identified during pre-service inspections | • 01 x Certified Heavy equipment Mechanics<br>• 01 x Uncertified Heavy equipment Mechanic<br>• 01 Certified power & Auto-Electrician | ***Schedule*** | ***Engine*** | ***Perc*** | ***PP*** |
| | | | | Cleaning & Testing | 1.5 | | |
| | | | | Weekly | 1.0 | 1.0 | 2.0 |
| | | | | 250hrs | 1.5 | 1.5 | 2.0 |
| | | | | 500hrs | 1.5 | 1.5 | 2.0 |
| | | | | 1000hrs | 2.0 | 2.0 | 2.0 |
| | | | | 2000hrs | 2.0 | 2.0 | 2.5 |

6.4 Lubrication and Hydraulic System

Lubrication is the process of using a lubricant to reduce friction and wear between two surfaces in contact. Lubricants can be solids (such as molybdenum disulfide $MoS2$), solid/liquid dispersions (such as grease), liquids (such as oil or water), liquid-liquid dispersions, or gases. Adequate lubrication allows for smooth, continuous operation of machine elements, reduces the rate of wear, and prevents excessive stress or seizure of bearings.

At Mega Mine, underground mechanized machines are lubricated when they are under maintenance, breakdown or in operation when instruments or gauges show low level of lubricants. Management of oil for components such as engines, transmission, axles, and transfer boxes receive adequate attention. Nevertheless, the greasing of components such as H-frames, drivelines and other articulation points seem not to get the attention they deserve. This could be seen from the continued failure of H-frames, oscillation cradles and drivelines.

Usually, when bushings for cradles and frames fail due to lack of lubrication, the parent structure is worn out, and the bore becomes too big to provide a bearing fit. To this effect, the steel structure is repaired by building the bore by arc welding and later machining to size using a line-boring machine.

Though the process of rebuilding machine structures through welding and line boring brings the bearing seat to normal or near normal dimensions, the lifespan and strength of the frame is compromised due to heat. This is mainly due to the thermal gradients which happen in the welding processes, welding residual stresses and geometric imperfections are normally introduced into the frame causing distortion. Nonuniform expansion and contraction of the weld metal and the surrounding base metal create distortion during the welding process, which occurs throughout the heating and cooling cycles. Heat produced during welding affects steel in several ways such as causing metallurgical and structural changes like distortion and residual stress, which can shorten the life of the welded structure. The toughness of the weld metal is therefore influenced by heat input, chemical composition, microstructure, and weld cooling rate. With no proper stress relieving process on site, the metal structure is weakened and likely to fail.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 04, April-2025

With reference to Mega Mine Planning Office Equipment Performance Sheets, hydraulic components which exhibit a higher failure rate include hydraulic hoses, pumps, valves, and cylinders. The valves inspected were found with stuck spools. Foreign particles in oil were found to be responsible for this condition.

Oil is carried around in plastic containers to locations underground where machines operate from. Some containers were not adequately sealed, yet other containers had cracks, a recipe for contamination.

Loaders were also found to be tramining ore and waste longer distances, a situation that contributed to failure of pumps and cylinders.

From the interviews conducted, it was stressed that Loaders were used to haul materials for a longer distance when the availability of Dump Trucks was low.

### 6.5 Machine Interlock System Management

In isolated instances, it was observed that when a machine had broken down underground due to a component failure such as an interlock switch, the component was bypassed on what was termed “temporally emergency basis” to move the machine out of the way of other vehicles. However, due to pressure of work, corrections to such initiatives were not made and ended up being permanent solutions.

An interlock can be defined as a device that prevents inappropriate maneuvers or adjustment of certain systems. They also provide safe start and stop to equipment systems and provide safety checks like cutting off the engine when engine oil levels are low. In the context of safety, interlocks can prevent a user from making unsafe actions or minimize the hazard of unsafe actions by rendering the machine in a safe condition when an unsafe maneuver occurs. Bypassing systems usually lead to failure of critical components which are not protected due to the absence of active interlocks.

No written instruction, procedure, or documentation in relation to interlock or system bypass was available on site. From the Accident Prevention document (FDR Safety) posted by Taubitz (2013), a question is posed as to what organizations and individuals do when they find an injury or near miss situation where an interlock or other safeguarding device is bypassed. This question should cause management to take serious measures against bypassing equipment components and systems.

Machinery fault diagnosis is one of the key techniques for continuous maintenance, which can help avoid abnormal event progression, reduce equipment downtime, forecast residual life, and reduce productivity losses. In turn, these can help avoid major system breakdowns and catastrophes. However, because of the complexity of the new generation underground mobile equipment, effective fault diagnosis has become a key component of equipment maintenance. Machines inevitably generate different faults of varying degrees because of complex and severe conditions, such as heavy load, high temperature, and high speed and they also trigger other warning signals such as low-level status of fluids, high component or system temperature, and other associated indications. As such, bypassing such warning activation components and systems could pose great danger to the machine operations as well as personnel. The situation at Mega Mine was eminent as on several occasions faultfinding was a challenge when Technicians conducting faultfinding were not aware of the bypassed component or system.

### 6.6 Tyre Management

Tyres are one of the major cost drivers in a mining operation and at the same time a severe safety hazard due to their mass and stored energy, however, though components such as engines, transmissions, differentials to name a few are closely monitored, tyre performance at Mega Mine receives less attention. Stressing the importance of tyre management, Galatia (2020) indicates that tyres are one of the key mining cost drivers as well as a major component on a machine, hence, they need to be managed effectively. On the other hand, Yadav, Gupta, and Kumar (2020) state that it is necessary to have a well-defined performance measure (PM) to monitor heavy mining equipment tyre performance. However, Mega Mine does not have an effective tyre management strategy to clearly define the selection, operation, maintenance, storage, and disposal (i.e., whole life cycle) of tyres, rims, and wheel assemblies.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 04, April-2025

The mine has a tyre handling machine equipped with all the necessary safety features. Additionally, all tyres are inflated from a safety cage, this makes handling of tyres safer. Nevertheless, some concerns were noted:

i. There is no documented system of understanding the influence of the operational environment on tyre life and safety, tyre selection, wheels, and rims management.
ii. The inflating cage is available at the workshop, but there is no tyre yard where tyres could be properly stored according to tyre condition; ready for use, scrapped, awaiting inspection and reusable etc.
iii. There is no formal condition monitoring such as non-destructive testing of wheel assembly components.
iv. There are only two Tyre Fitters who alternated between their Roster Leave.
v. There is inadequate data analysis of the failed tyre by the Planning Section. The data submitted to Planning by the maintenance personnel is not fully analyzed to pave the way for further analysis and management decision making. Additionally, the failure modes are not properly highlighted on the tyre check sheet. Most of the tyre failure reports indicate "worn-out" as cause of failure. This makes it difficult to know and address the root cause of failure.
vi. The personnel handling tyres have no formal training in tyre management, and this makes it difficult for them to understand such concepts as mechanisms of tyre fires, explosions, and other tyre management techniques.
vii. There is no regular checking and documenting of tyre pressure and wheel nut status. Correct tyre pressure is critical in minimizing side wall cut as well as maintaining heat at a lower level inside the tyre.
viii. Due to not having a consolidated Tyre Management Crew, the number of breakdowns relating to broken wheel studs is high. This is because studs and nuts are not checked on a regular basis.

Plans were, however, underway to construct a tyre shade which would be clearly demarcated and on the other hand, training of personnel involved with tyre handling was being pursued.

### 6.7 Backlog Work Management

The backlog is the amount of identified work deferred to a later time. When maintenance personnel are carrying out planned or unplanned work on a machine, there are certain faults on a machine that may not require immediate attention due to time constraint, manpower shortage or nonavailability of spare parts as well as the lower severity of the fault. These are faults that cannot affect a machine or personnel in the short run. The Technician lists these tasks on a check sheet which is later handed over to the Planning Office for review and scheduling. Peters (2015) summarizes backlog work as work that has not yet been completed. Thus, putting the listed definitions into a single context, maintenance backlog comprises both preventive and corrective maintenance tasks, as well as quality inspections or any other activity that is indispensable for the proper functioning of the equipment.

Therefore, the standard practice of backlog management is such that, when it is necessary to have maintenance work performed that cannot be accomplished immediately by standby or running repair personnel, a job request or work order is prepared. The work order provides the means to both request maintenance work and to plan and control it.

The work order form should provide sufficient space for the following information:

i. Date, originator, approvals, equipment identification and cost center.
ii. Description of the work required and any special instructions.
iii. Material and labor estimates.
iv. Actual man-hours worked, dates and major parts used.

It is imperative that all work identified as being required, unless it is standard schedule maintenance activity or emergency breakdowns of a short duration, be documented in a written work order. Once a work order request has been submitted and the necessary work planned by the Planning Section, the job is placed on the backlog. All backlogged work should be completed whenever a piece of equipment is taken down for maintenance or when any form of opportunity maintenance arises.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 04, April-2025

Nevertheless, at Mega Mine, the system of backlog was not sufficiently managed, it lacked consistency. Though in certain instances, maintenance personnel identified backlog work and reported such findings to supervisors, the system lacked formal communication. This made tracking of backlog work by the Planning Section difficult. Backlog work is indicated only on the maintenance check sheet and usually receives less attention as much attention is directed to entries for planned maintenance activities. On the other hand, the Planning Office does not follow up on backlog work to determine the required resources to schedule work.

6.8 Breakdown Response

Whenever there is a breakdown underground, the Operator communicates with the Surface Control Room personnel who later communicate the breakdown to the maintenance personnel from the Surface Workshop. Though the communication may be effective, the Maintenance personnel have only one vehicle to attend to all breakdowns on surface and underground. This phenomenon leads to delays in attending to breakdowns. This is evident from the observed extended Meantime To Repair reports.

6.9 Failure Analysis and Investigation

In summary, Failure Analysis is a process of investigating failure to determine the root cause, typically with the aim of taking corrective action to fix the problem and mitigate against further failures. On the other hand, failure analysis helps to prevent future assets and product failures as well as protecting against potentially dangerous risks to people, equipment and the environment.

However, at Mega Mine, no root cause analysis is conducted for any form of failure whether repeated or unique. Therefore, there is not enough data to ascertain whether failure occurred due to manufacturing, operational error, maintenance or material defect.

6.10 Major Component Management and Condition Monitoring

Equipment Major Components are one of the fundamental cost drivers in a mining operation and success in managing them is crucial in achieving low maintenance and production cost of the equipment. Whereas Condition Monitoring is a proactive maintenance strategy that continuously monitors equipment and systems, enabling early fault detection and timely maintenance actions. Condition Monitoring prevents or minimizes unplanned downtime, maximizes equipment uptime and reduces maintenance and production cost.

Observations from the Mine are such that there is no equipment nor component life tracking, components are only replaced when they fail. Additionally, no condition monitoring of any kind is carried out.

When operating Mechanized equipment, fluid analysis is important for the health of a machine. However, this is not conducted at Mega Mine. Fluid analysis is an essential component of Mechanized Equipment as it represents a routine procedure that assesses oil health, oil contamination, and machine wear. The vital role of an oil analysis program is to check whether critical equipment components operate as expected.

6.11 Planned Maintenance Execution

Well-planned, properly scheduled, and effective communication can accomplish more work, more efficiently, and at a lower cost. Work properly prepared in this manner disturbs operations less frequently, and is accomplished with higher quality, greater job satisfaction, and higher organizational morale than jobs performed without proper preparation. Thus, planned maintenance refers to maintenance work that is performed with advance planning, foresight, control, and records.

Mega Mine has a Maintenance Section, nevertheless, this Department is managed by non-technical personnel who have little or no understanding of the equipment. They raise and issue check sheets to the maintenance personnel to follow while carrying out maintenance. Though Technicians are given these maintenance check sheets to follow during planned maintenance, several planned maintenance activities are completed beyond the planned duration.

One of the contributing factors to delayed completion of planned maintenance work is the inadequacy of the system to hold the Technicians accountable for the delay in completing planned maintenance. When work is completed, the technician hands in the completed check sheet to the Maintenance Planning Office without any written or verbal explanation of why the task took longer than planned. This does not provide sufficient opportunity for improvement in time management. The other observation is that, when labor is allocated to a machine, no one is appointed to

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 04, April-2025

oversee the task from commencement to final completion of the planned maintenance. Everyone falls under the auspice of the Foreman who moves around from maintenance, breakdown, and stores, giving him less time to monitor and control scheduled maintenance work. Additionally, there is a minor or no accountability for rework. When a machine breaks down prematurely after planned maintenance or repair, no one is held accountable for the failure. If not properly checked, this phenomenon could lead to negligence and what the writer may term "accepted sectionalized incompetence" where incompetence becomes an acceptable norm within the Section.
The other factor leading to delayed completion of planned maintenance work is the nonavailability of a storage facility of maintenance parts within the Workshop area. Several times, due to this deficit, parts are drawn from Supply on the actual planned maintenance day. This creates stoppages or slows down work as the attention is split between looking for spares and carrying out the actual maintenance task.

6.12 Interaction Between Maintenance and Planning Section
Though the maintenance personnel are part of the Planning system, the observed trend at Mega Mine is such that Planning and scheduling is more driven by maintenance personnel than the Planning Section. This phenomenon places the Planning Division into only carrying out what may be termed as Clerical work. In short, there is a disconnect between the Planning and Maintenance personnel on the Workshop floor. The Planning Section does not show much leadership in directing equipment maintenance, planning and scheduling. This could be attributed to the Planning personnel not having adequate technical knowledge of the equipment and maintenance processes.
The whole purpose of planned maintenance is to account for work that will inevitably need to be performed so it can be properly scheduled. However, this is not the case with documentation reviewed from the Planning Section, several additional unplanned works on top of the previously scheduled work were noted from the documents, this signifies that the preventative maintenance is not properly matched with schedules.
The tools for collecting and inputting data are available at the Mine, but the level of organizing and analyzing the data is not up to standard. It is difficult to adequately track the history of machines because data is either not provided to Planning or the Planning personnel do not input the data. One example is when machine hour meter is replaced by maintenance personnel, the planning staff start counting machine life from zero without taking into consideration the previous service hours. This leads to having two or more different lifecycle information for a single unit.

6.13 Equipment Performance Reports and History
Accurate equipment performance reports are a major component of a Mechanized Section as reports make it possible to track the condition of equipment over time. This allows for proactive decision-making to prevent equipment failure and to identify trends.

Understanding the performance of equipment enables the Maintenance personnel to:

i. Identify trends
ii. Predict potential failure
iii. Allocate resources appropriately

However, Mega Mine Maintenance Planning Section only calculates and presents machine availability and utilization figures to the Mine Management monthly. No equipment reliability statics are calculated nor presented. The other performance indicator presented is Overall Equipment Effectiveness (OEE). Nonetheless, this statistic is not clearly understood by both the Planning and Maintenance personnel as wrong inputs are used for calculation.
A critical data-driven approach to maintenance planning allows the Maintenance Section to proactively schedule maintenance activities, reduce unplanned downtime and associated production losses.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 04, April-2025

### 6.13 Maintenance Strategy

A maintenance strategy is a comprehensive blueprint for how organizations minimize equipment downtime, regulate maintenance costs and ensure processes operate at or near capacity.

There is no formal Maintenance Strategy at Mega Mine, and this leads to maintenance lacking a clear objective. Work execution is personality driven (driven by the individual) with loose coupling of roles and accountabilities allowing informal sub-systems to become acceptable responses at the Mine. Relying on “personalities / individuals” to deliver acceptable maintenance outcomes brings with it significant known and unknown risks.

The rules, relationships and processes necessary to deliver effective maintenance outcomes are not clear and consequently, people make their own rules to suit the circumstances which may or may not align with Mega Mine Management expectations. Additionally, the lack of systems of work lead to duplication, rework and waste, all of which add unproductive costs to the Mine, contribute to frustration within the maintenance and production groups and divert resources away from activities that could increase machine health in the short term and shore up revenue generating capacity in the medium term.

### 6.14 Computerized Maintenance Management System

A Computerized Maintenance Management System (CMMS) streamlines maintenance by managing orders, tracking assets, and improving efficiency with real-time data and analytics. The software automates the scheduling of inspections and maintenance, preventing the occurrence of maintenance problems and expensive repairs. Switching from reactive to proactive maintenance also extends the life of equipment while reducing the overall operating costs of the maintenance function.

However, the Maintenance Section at the Mine uses a CMMS which is a mere data recording and reporting tool. Furthermore, the system cannot generate equipment reliability figures nor calculate component life or machine life. Whilst Mega Mine Maintenance personnel may be comfortable with this approach, as the mine expands and production pressure increases, the reliability of the mobile equipment would be critical and the existing personality / individual driven approach to maintenance may not be sustainable or desirable.

This CMMS could have been accepted on the mine due to the fact that personnel running the Planning Section are non-Technical and may not fully understand the basics of maintenance planning. The usefulness of CMMS output (schedules, reports or performance indicators) is determined by the relevance and accuracy of the base data. Importantly despite the name, a CMMS does not manage the work and does not manage the people – two critical ingredients for successful maintenance outcome. That is why it is important to note that organizations often rely on the “tacit knowledge” of Subject Matter Experts (SME) or that knowledge which comes with grey hair and experience to keep such systems running efficiently. Thus, a Planning Section must be run by SMEs in the relevant field of operation.

## 7. PROPOSED MITIGATION

Having reviewed several areas (elements) in the mine maintenance system, a summary of the findings regarding each element has been presented and recommendations proposed:

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 04, April-2025

| **Element - Lubrication and Hydraulic System Management** | |
|---|---|
| Purpose | The purpose of this element is to clearly define the requirements for an effective Equipment lubrication management system to ensure a full understanding of the process together with the required facilities, equipment, skills and manpower requirements. |
| Background | There are a high number of failures associated with lubrication and the lubricants cost has always been above the monthly budget. |
| Mitigation | The first step towards lubrication management is to have a Lubrication Section whose responsibility is to ensure the overall performance of equipment lubrication systems. For easy mobility, the Team should have at least one mobile lubrication cassette which should go around workplaces underground to lubricate machines in service. Emphasis should be placed on greasing pins and bushes. On the other hand, Operators should be provided with grease cans either foot or pneumatically operated to lubricate critical points of a machine as and when required. To ensure compliance, Operators should be issued with lubrication checklists which should be checked by senior personnel such as Shift bosses at the end of each shift. In instances where a machine is driven through water, the Operator should stop the machine and grease critical points such the dog-bone and H-frame swivel parts. In all cases, records of lubrication must be submitted to the Planning Office daily.<br>When using equipment with automatic lubrication system, Technicians must physically check to ensure that grease reaches all sliding/rolling points fed from this channel. During the time of the study, two failures were noted where bushes failed due to lack of lubrication on an automatic system. The system was showing "health", but the lubricant was not flowing to the H-frame bushes.<br>Additionally, the selection of grease for underground machines should be accurate as underground machines operate from waterlogged and high temperatures areas. Therefore, the maintenance personnel should choose a grease which will withstand high temperatures, high pressure, and wet conditions.<br>A wrong selection of grease will increase the frequency of greasing and at the same time may not provide adequate cushion for the sliding/rolling parts.<br>Numerous hydraulic component failures were analyzed, and possible failure causes identified. The most prominent cause identified is contamination of oil when filling the hydraulic tank. The filling of hydraulic oil into the tank is supposed to be through the filling pump which is mounted on the machine. However, several machines inspected had these pumps in a non-operational state. This condition leads to the filling of oil through the inspection hole making it easy for any foreign materials to go into the oil reservoir because this access has no filter.<br>It is therefore recommended that the oil filling pumps on machines be repaired or if they cannot be repaired, new ones should be procured and installed. Moreover, the acquisition of a Kidney machine to clean oil from machines while on service will be an added advantage to keeping the oil in machines clean. This initiative has the potential to lower oil consumption by reducing the frequency of oil changeout. Condition monitoring of oil can provide a duo benefit to the maintenance department. Firstly, it can help with timely replacement of parts and secondly, it can assist in minimizing oil changes. Oil can only be changed if the results of the analysis indicate caution in a specific parameter of oil. It is therefore recommended that Mega Mine identifies an efficient laboratory within the region or procure its own oil analysis equipment. Additionally, maintenance and operation personnel should avoid carrying oil in open containers. Properly sealed oil dispensing units should be used.<br>The mining department should avoid using Loaders for hauling material over a longer distance to avoid unnecessary stress on the machine hydraulic system. |
| Summary | For effective results, a Lubrication Section should be constituted with clear responsibility and accountability. Additionally, the Section should be provided with adequate tools and materials. Personnel from this Section should be |

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| | given authority to stop a machine and inspect lubrication points where need arises. |
| **Element - Machine Interlock System Management** | |
| Purpose | This element is discussed to help maintenance personnel find an effective way of managing interlocks on machines. |
| Background | The bypassing of interlocks on machines was noticed and the maintenance personnel said this was done on a temporal basis. However, because there is no formalized system to manage such conditions, these temporary maneuvers ended up becoming permanent solutions. |
| Mitigation | There are specific instances when certain components or systems can be bypassed or deviated from standard. One example is when a machine interlock fails disabling a machine in a production area, the interlock may be bypassed to move the machine out of the way or drive it to the workshop. It should therefore be noted that such maneuvers should be temporal and should be corrected before the machine goes back into operation. Nevertheless, most of the time such bypasses are not corrected. It is recommended that a monitoring system be introduced in form of a book or what may be termed as a "bypass logbook" which should be completed by the Technician and approved by the Foreman or Superintendent. This document should be handed over to the Planning Office for emergency correction work to be scheduled. It may even be an added advantage to have tags for hanging or sticking on a machine with a bypassed component or system. |
| Summary | Interlock devices may present some challenges and limitations for industrial safety. For example, workers may attempt to bypass or defeat them to save time or avoid inconvenience by using tools, magnets, wires, or other methods. Malfunctioning due to such factors as wear and tear, improper installation, environmental factors, or even sabotage, interlocks may give false alarms or unexpected restarts of the machine functions. Therefore, to ensure the safety of equipment and personnel, it is recommended that risk assessment and hazard analysis of the machine and work environment be conducted before a machine is introduced to the Mine. This will help determine the appropriate type, level, and frequency of interlock devices needed, as well as any potential failure modes and consequences. Furthermore, it is important to follow the manufacturer's instructions for installing, operating, and maintaining interlock devices, making sure they are compatible with the machine and power source. Maintenance personnel and Operators should be trained and educated on the purpose and function of the interlock devices, emphasizing the importance of safety rules and procedures. Additionally, regular monitoring and inspection of the interlock devices is necessary to repair or replace any faulty or damaged parts. Finally, it is always important to review and update the interlock devices as needed to reflect any changes in the machine, work process, or safety standards. |
| **Element - Tyre Management** | |
| Purpose | This component clearly defines the importance of mining equipment tyres and presents initiatives which could assist in managing tyres effectively. |
| Background | The Mine operates without a formal Tyre Management System. Tyres are managed by personnel who have very little knowledge of Tyre management. Once assembled and mounted on a machine, there is no follow-up on the performance of the tyre, nor any report generated to show the performance. |
| Mitigation | The Starting point for an effective Tyre Management is the implementation of a Tyre Management Crew which should be well trained in tyre management. This should be considered seriously because working with tyres for heavy underground equipment is potentially dangerous because of their large size and mass, the magnitude of air or gas pressures, and the presence of combustible materials. The uncontrolled release of stored energy can have serious, even fatal, consequences.<br>Secondly, the Mega Mine Maintenance Department should adopt a risk management approach and develop a documented tyre management plan specific to the Mega Mine site, with appropriate controls to manage risks.<br>This management philosophy should include elements such as:<br>i. Fit-for-purpose equipment: The equipment to be selected should be safety-in-design and replacement or maintenance parts easily available. Additionally, the equipment must be adequate to prevent improvising which usually leads to accidents or damage to tyre components or the tyre itself. Tyre Technicians must be able to maintain this equipment or tools. |

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 04, April-2025

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| | ii. Competent personnel: As already indicated, tyres pose a great danger to personnel, therefore, personnel involved with the management of tyres should have adequate training and experience. Several Tyre OEMs provide this kind of training.<br>iii. Safe systems of work: To ensure maximum safety, procedures to all critical activities such as tyre inflation, tyre mounting, and tyre pressure checking should be drawn up. This information should be provided to all personnel charged with the task of managing tyres.<br>iv. Data Collection: Efficient data collection and analysis is required.<br>It is worth noting that partially inflated tyres lead to side cuts and in certain instances, tyres may develop excess heat and catch fire. Therefore, tyre pressure management is essential. Before issuing or mounting a tyre, the tyre Technician must ensure that the pressure is correct. Additionally, there is a need for the tyre Technician to carry out daily checks of all the tyres which are on operating machines. The date and pressure reading should be written on each tyre to indicate the tyre has been inspected and certified fit for use.<br>When a tyre replacement sheet is completed by the Artisan, the Foreman or Maintenance Specialist must go through the sheet to ensure that all the information is entered correctly. Efficient information, especially the description of failure, is vital for decision making by management. For example, increased side cuts will prompt mining management to inspect areas of tight bends and maintenance personnel will look at tyre pressure management.<br>When tyre check sheets are taken to the Planning Office, Planners must group the failure modes and develop graphs to show trends of each failure category. This makes it easy for both mining and engineering personnel to make quick and informed decisions. Additionally, accurate tyre performance data assists with predictive maintenance and performance optimization.<br>In addition, the Tyre Crew should carry out daily inspection of the wheel studs and nuts. Loose components must immediately be tightened. During the period September 2023 and November 2023, a high number of broken wheel studs were recorded for Dump Trucks. Some wheel assemblies had more than three quarters of the studs broken from one hub assembly in a single breakdown. Though underground tight conners contributed to this kind of failure, lack of inspection and retightening of loose nuts is the major factor. The Department should also have a rule regarding the minimum number of nuts on a single hub a machine can be allowed to operate with. Below a certain number of wheel nuts, the machine should be parked, and missing nuts replaced.<br>On the other hand, the Supply Department, with the help of maintenance personnel, must ensure that tyres are responsibly sourced for the right application and from credible and approved Suppliers. Any tyre chosen as an alternative should be of the same size, construction, and service description as the original tyre. Thus, the equipment and tyre manufacturers' data should be consulted before using a tyre with a different specification. Other than just the tyre size, the aspect ratio is equally important. Most underground machines such as Drill Rigs have tyre data engraved on the chassis.<br>Since the Mine deals with a variety of tyres, it is important for Supply Chain in conjunction with the Maintenance personnel to develop a tyre chat to display tyre sizes and the rest of the tyre information. This is to minimize the chances of error and ambiguity in tyre selection. Above all, training for the Tyre management personnel by the tyre manufacturer is key for Mega Mine.<br>Though tyres are stored at the main Stores yard, there is need for a tyre workshop to be constructed near the mechanized Workshop which should be well demarcated for, new assembled tyres, reusable tyres and components, scrapped, loose tyres, and tyres under investigation/inspection. A small room will be required to be equipped with recommended tools and smaller tyre accessories such as valve stems and cups. |
| Summary | Effective Tyre Management is essential for maintaining the safety of personnel and equipment, it enhances safety, reduces risks and lowers the operating cost by maximizing the use of tyres and reducing unnecessary production stoppages. |
| **Element - Backlog Work Management** | |
| Purpose | The purpose of this element is to clearly define the requirements for work identification to enable timely and accurate |

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 04, April-2025

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| | identification, reporting, recording, classification, prioritization and execution of tasks. |
| Background | Clear concise processes for identifying work associated with an asset are fundamental to reducing the delay / disruption effect of breakdown and un-scheduled work. Confidence that work is identified, captured and prioritized in a systematic manner provides comfort that work outstanding for an asset is known, documented and relevant details are available for planning and execution purposes. However, there is no Backlog Management System at Mine. The available Inspections and Service performed do not indicate any backlog work and in certain instances, check sheets are not accurately completed. Completed service check sheets are signed by the Foreman, nonetheless, underlaying defects or potential failures causes are not recorded. |
| Mitigation | For backlog work to be managed effectively at Mega Mine, both the Maintenance and Planning personnel must have some form of training in identifying, recording, weighing, planning and scheduling of backlog work. If there is no one on site to provide such kind of training, external consultancy should be sought as backlog management is essential for any Mechanized operation.<br>Both Maintenance and Planning personnel must understand that clearing the maintenance backlog is a crucial part of effective maintenance management of equipment. Therefore, tasks identified and entered as backlog should be scheduled and corrected at the earliest possible time. In maintenance backlog, neglected tasks become impossible to manage, eventually causing more breakdowns and extreme downtime. This can jeopardize the safety of employees.<br>When backing input and tracking is properly done, it can be used as an indicator to show whether the Section has too many staff or too few staff. For instance, if there are always too many backlogs, it shows that more maintenance personnel are required. However, if the number of maintenance backlogs is too low, it may mean the Section is overstaffed. Nevertheless, Mega Mine should watch such conditions as this could also mean the maintenance personnel may not be entering backlog work. Therefore, regular inspection by Foremen and Maintenance Specialists should be enhanced.<br>Mega Mine should always ensure that there is a balance between maintenance work and maintenance Technicians. Since a lack of maintenance backlog tracking was observed at the Mine, the Planning Office needs to commence inputting all backlog work into the already available Computerized Maintenance Management System (CMMS). This will allow for easy tracking of backlog work. At the same time, the Planning Section, with the help of maintenance personnel, needs to have a system of prioritizing backlog work. A hierarchy of faults should be developed. |
| Summary | Inspections carried out within the Workshop and other work areas identified numerous issues underlying the opportunity to refine the processes used to identify, notify and record machine defects to ensure that relevant details are available for planning purposes. Improving the quality of pre-start inspection, daily inspection, breakdown and service sheet documentation will promote the identification of issues requiring action and a more comprehensive understanding of machine back log / machine health. |
| **Element - Breakdown Response (MTTR)** | |
| Purpose | The purpose of this element is to clarify the need to reduce the meantime to repair for the major underground equipment. Accurate tracking of response and repair times is critical as downtime can cost money in terms of revenue lost, and productivity lost. Therefore, the quicker the maintenance Team responds and resolves issues, the lesser the equipment downtime. It is also important to perform a postmortem analysis, identify the root causes of each incident, and make improvements focused on cutting down breakdown incidences and repair time. This will increase equipment availability and reliability. |
| Background | The Section has only one breakdown response vehicle to cater to breakdowns and expedite spares both underground and surface. When there was a breakdown underground, the machine operator communicated by radio to the surface control room. The control room then informs the maintenance personnel. There is no analysis of the reaction time to breakdowns nor conducting failure analysis to determine the root cause of failure. Failure analysis is one way of minimizing failure occurrence. It helps the maintenance personnel identify components or systems that are prone to failure and take steps to improve their reliability and maintainability. By reducing the number of incidents in a specific period, the maintenance section can spend less time repairing failed equipment, hence, increasing equipment uptime. |

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| Mitigation | The following will assist in improving MTTR:<br>i. Improve Preventive Maintenance: The section should incorporate backlog work and routine services into the maintenance plan to address potential breakdowns before they occur. The planning Section must collaborate with the maintenance personnel in identifying potential failure causes. This can be accomplished by the maintenance personnel highlighting all faults observed on a machine during maintenance or breakdown. Those faults which could be managed immediately should be resolved and those that may not affect the operation of the machine should be documented as backlog work and the Planning Section should weigh them and schedule appropriately. This can reduce the number of breakdowns and improve equipment reliability.<br>ii. Technical Training: The company should improve the Training and Development Department. During the time of research, there were no technical personnel at the Training and Development Department. The Department only provides employee and visitors induction as well as the issuing of heavy equipment and light vehicle driving licenses. If the company cannot provide technical skills to the 'Artisans', it will be wise to send these employees for training outside the company. The company needs to create a technical Team with the ability to perform maintenance tasks faster, more efficiently and effectively. Hiring of more Expats will be an added advantage as they can provide situated straining to the Local employees.<br>iii. Condition Monitoring: There is no conditioning monitoring program at the Mine Maintenance Workshop. No oil analysis is conducted for the fleet. When running equipment where rolling contact is involved, it is imperative to understand the behavior and effects of friction, lubrication and wear phenomena for interacting surfaces in relative motion within the equipment. To understand these trends, tribology testing is necessary. As such, when dealing with mechanized equipment, oil analysis became an essential element of maintenance because it reveals the wear characteristics of expensive components such as engines, transmissions, final drive and differentials. Thus, oil analysis helps to identify problems in the machinery such as abnormal wear, lube oil degradation, contamination of harmful agents, etc. To this effect, it is suggested that the Mine procures oil analysis equipment such as MinLab 153. The Mine is in a remote part of the country and there is no oil laboratory nearby. If the samples are sent for analysis in other towns, the response time defects the whole purpose.<br>iv. Spares Inventory Management: The Mechanized Workshop does not have a satellite store for keeping spare parts and consumables such as filters. Each time there is a need for parts, one must raise a requisition through the Planning Office and pick up parts from the main Store which is about a kilometer from the Mechanized Workshop. The Department should develop a satellite store within the Workshop for keeping fast moving parts and special tools. It is also cardinal for the Mine to procure ERP software to ensure that critical spare parts, tools, and materials are always available as needed, so that equipment uptime is not heavily compromised by a shortage of these spare parts. The Department should also consider hiring a dedicated individual to manage parts (Materials Coordinator). This should be a person with sufficient knowledge of the operation of heavy mobile equipment.<br>v. Regular Data Analysis: the Section through the Planning Office should conduct regular data analysis to better understand the recurring performance issues and drive improvements in repair scheduling to increase equipment up time. It is also recommended that the maintenance personnel should have brainstorming sessions to determine the root cause of repetitive and unique failure modes.<br>vi. Enhanced Communication: There must be effective communication between the maintenance personnel and other Departments such as Mining and Supply Chain. This can be accomplished through an effective ERP system.<br>vii. Regular Audit of Equipment: It is important to carry out a periodical equipment audit to ensure the |

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| | equipment is in good order as this helps in identifying and resolving potential breakdowns. Occasionally, it is advisable to use external auditors to inspect machines and give an independent report.<br>viii. Computerized Maintenance Management System: The mine should acquire effective CMMS to consolidate and automate activities such as order management, equipment performance monitoring, inventory tracking and maintenance scheduling on a single, easy-to-use-data driven platform.<br>ix. Maintenance Procedures: The Section needs to formulate a well-defined repair plan which should formalize maintenance procedures to give guidance to maintenance personnel in the repair process. This will make the Section maintain standards for quality and safety of personnel as well as equipment. With this in mind, the Section should also develop a Maintenance Strategy. |
| Summary | A cursory review of machines on breakdown and around the workshops identified numerous issues underlying the opportunity to refine the processes used to identify, notify and record machine defects to ensure that relevant details are available for planning purposes. Developing the quality of pre-start inspection, daily inspection and service sheet documentation will promote the identification of issues requiring action and a more comprehensive understanding of machine back log / machine health.<br>Reaction time to breakdowns or Mean Time to Repair is a significant metric for evaluating and estimating response times and the overall success of maintenance personnel. Management should use MTTR data as a Key Performance Indicator (KPI) to determine the efficiency and effectiveness of the maintenance Team. A low MTTR is a sign that the Section has a successful maintenance program and is achieving its goals, however, a high MTTR shows that maintenance is not adequately addressing maintenance issues. This suggests that there is need for improvement in maintenance processes, training programs, or resource allocation strategies. |
| Element - Failure Analysis and Investigation | |
| Purpose | The purpose of this element is to explain the requirements for determining the immediate cause/s and contributing factors of failures in Mechanized Equipment. |
| Background | Despite the repair effort by the maintenance personnel, equipment failure occurs and whilst failure is regrettable, effective failure investigation provides opportunities to better understand the failure cause to minimize the risk of similar failure events and leverage future performance. However, there is no evidence of failure analysis being conducted at Mine. |
| Mitigation | Failure analysis is carried out to investigate and understand the failure mode. Most importantly, why a component or system failed. It is significant to know if the failure is due to design flaws, manufacturing or material error or if the equipment was used outside its design criteria or exceeded its useful life. The Mine must categorize the nature of failure according to severity and uniqueness of failure. Failure should be given categories starting from minor to severe and from here failure requiring analysis should be determined as not all failure requires a deep investigation. To this effect, the Mine should send some maintenance personnel for failure analysis training or bring an expert to site to conduct training. If failure analysis is correctly done, it will help the maintenance personnel to:<br>i. Understand the root cause of failure: Each component or system has its own set of failure mechanisms, and understanding these flaws can provide a better way to manage the equipment or system. It allows the maintenance personnel examine failure in detail and devise prevention measures.<br>ii. Take corrective action to prevent recurrence: Once the cause of failure (root cause) is identified, accurate and inexpressive corrective action can be taken.<br>iii. Improve maintenance practices: Historic failure analysis will assist in identifying potential failure before occurrence, allowing maintenance personnel to take proactive measures to prevent failure. It also helps identify areas of improvement in maintenance operations and management, allowing maintenance staff to make changes to improve efficiency and reliability of equipment.<br>iv. Reduced breakdowns: Minimize the number of stochastic and repetitive failures of major components and systems by identifying the actual cause of failure and finding solutions to such failure. |
| Summary | Identifying the root cause of individual failures enables management to implement appropriate corrective actions to limit the occurrence of repeat failure and identify targets for reliability management processes. Failure investigation is also a useful first step towards continuous improvement and presents a significant opportunity for an organization to learn what went wrong and develop its corporate memory. The maintenance personnel should take failure analysis as an ongoing process, rather than a one-time event. It is essential to create a culture of continuous improvement within the Maintenance Organization, where all participants are encouraged to share their ideas and feedback for improvement. Brainstorming must be encouraged. This can be achieved through regular training and workshops, cross-functional collaboration, and open communication channels. |
| Element - Major Component Management and Condition Monitoring | |
| Purpose | The purpose of this element is to clearly define the requirements for developing a “whole of life” approach to the management of equipment major components and to establish a performance baseline for all components installed on a |

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 04, April-2025

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| | machine. |
| Background | There is a lack of formal processes for regular verification of equipment major component life. Component life and condition are not monitored, and this creates a situation where components fail unexpectedly creating excessive machine downtime. Finance cashflow timing is equally affected as expensive components are bought at random when a component fails. There is no projecting of component life nor condition checks carried out to determine the deteriorating rate and retirement of a component. |
| Mitigation | For the Maintenance Organization to manage equipment major components effectively, the following should be carried out:<br>i. Define the component life goal: A component life is the period of satisfactory usage after which the likelihood of failure increases rapidly. With proper component management, a component is removed from the machine before failure in the interest of reliability. Therefore, the maintenance organization must define what it wants to achieve from individual components. The Mine primary goal in managing equipment components should be to ensure that the component management program is developed to ultimately decrease failure by increasing component efficiency through condition checks and planned replacement.<br>ii. Define component Strategy: The Maintenance Department must develop a component changeout strategy. This should be a specific course of action for achieving the component life goal. It should clearly indicate the actions to be taken from component commissioning right through the end of life. This should include the method of tracking components life, the budget, repair or buy new for replacement parts, maintenance or management of components, replacement time, manpower allocation (permanent repair team or ad hoc), build component rebuild Workshop or use one common workshop for maintenance and component changeout and finally, condition monitoring. The strategy must be made known to all maintenance personnel and management. This is to ensure the strategy does not compromise production. The changeout schedule must be agreed by both the maintenance and operations departments and the projected equipment outage time must be factored into the Mine Plan.<br>iii. Define Component Inventory: This is one of the most critical areas. In this study context, inventory refers to all the replacement parts meant for changeout and their associated accessories. Therefore, inventory is ‘Cash withheld’. To ensure an efficient utilization of these resources, a clear and precise component replacement plan should be drawn up to ensure resourceful utilization of these parts. Holding parts for a long time results in restricted cashflow, the working capital is eaten away, increases storage cost and the risk of stock obsolescence and spoilage is eminent. A proper component tracking schedule will show when each component is due for replacement and cost assigned to it. If a replacement component is refurbished, the refurbishment cost must be indicated to reflect the true cost of a changeout. Do not only consider the cost of major components only, but all part kits which go with these components must be considered.<br>iv. Establish a performance baseline for components: Components will either be new or refurbished. Therefore, the maintenance personnel using OEM information and their experience should determine the life cycle of each type of component. Condition monitoring will give good guidance to the component deterioration rate from which informed replacement decisions can be made. Other factors such as environmental, operational skills, and operating time must be considered in setting up component life.<br>v. Implementing an effective component tracking system: Component tracking is crucial because it provides total visibility of component performance and life. It allows for accurate replacement of components and enabling efficient utilization of resources, improving maintenance schedules and ultimately increasing productivity and profitability. The Mine therefore needs to develop an accurate computerized system of tracking components. The tracking should record the expected component life, the date the component is fitted, when the component is expected to be removed, component performance along its life cycle and the cost of replacing the component. If a component fails before the expected time, a comprehensive failure analysis should be conducted to determine the root cause. Condition monitoring plays an important part in component tracking, this should be conducted at regular intervals to ascertain the deterioration of the component. If the condition monitoring results show the component can work beyond the projected end of life, the component life can be extended, but it should be closely monitored.<br>vi. Establish Primary Component Replacement (PCR) Forecasting: Component replacement will assist the Mine to make a reliable component replacement budget. Each equipment component should be put on a table showing the installation date and planned removal date. The cost of the component should be clearly stated in the table. This table should cover a duration of one year. However, this table may cover a period of two or more years depending on the Maintenance strategy adopted.<br>vii. Planning and Scheduling: In a component replacement program, planning and scheduling are two closely related but different processes that are used to efficiently organize components and related materials, coordinate activities, and carry out the final replacement task. Through planning, the |

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| | Maintenance Section should clearly state the objective of the program, develop a replacement schedule of all components, assign several personnel to each replacement task, draw up a list of material requirements and allocate time to each task. After the planning is complete, work is scheduled. Thus, the date of replacement is set, duration of the task (start and end date) and there should be provision for any adjustments if required.<br>To ensure component forecasting and replacement is carried out effectively a computer aided system is required. |
| Summary | A disciplined approach to managing equipment major components from commissioning to retirement life ensures equipment remains fit for purpose, significant maintenance intervention is identified in advance and inventory is well managed. |
| Element – Planned Maintenance | |
| Purpose | The purpose of this element is to define the requirements for work planning to ensure a full understanding of the work together with the required facilities, skills, equipment, labor, materials and anticipated duration before work is scheduled. Effective planning prevents poor performance, enables effective allocation of resources, and limits the amount of rework. |
| Background | The Mine does not differentiate between planning (how work is to be completed) and scheduling (when the work is to be completed). The Maintenance Section focuses on scheduling and planning is seen to be aligned to Planned Maintenance Services only. The absence of a formal planning methodology creates a significant impact on the quality of maintenance and productivity of maintenance personnel at the Mine. |
| Mitigation | The Maintenance Planning Section must start with developing a Planning Strategy and outline all the tasks that the Section needs to undertake and the expectations from the maintenance personnel and the mining department.<br>Since the Department has no Reliability Section, the Planning Section must take up this role. The main reason for implementing Reliability Analysis is to ensure that condition monitoring and failure analysis of major components and other unique failures is conducted appropriately. Results of such analysis should be analyzed and shared with maintenance personnel for decision making. To this effect, the Planning Section must ensure that necessary condition monitoring tools and equipment are available on site. To ensure this task is accomplished successfully, a Reliability Engineer should be employed or one of the maintenance personnel should be trained by Reliability Maintenance experts to carry out Reliability Analysis activities on the mine.<br>The Planning Office must create a flow chat of Planning activities, more especially the movement of documentation. This will help the maintenance Section manage activities efficiently and be able to identify bottlenecks in the system such as delays in submitting work sheets. Additionally, it should be the duty of the Planning Office to ensure that documents are completed correctly and submitted on time. If the data on any document is not correct or some details are missing, the Planning Office must make an immediate inquiry. Furthermore, the maintenance personnel must ensure that the documents they submit to the Planning Office are correctly filled and handed in within the stated time.<br>The Job Card system must be emphasized as it is an essential tool for controlling major repairs, either planned or unplanned. Information on equipment identification numbers, serial numbers, total hours run, and hourly meter reading, where applicable, should be listed on the job card. Job cards should be arranged in order of priority and all backlog work that can be accomplished should be itemized and time assigned. It is important to prioritize tasks as this will help identify low priority tasks which can be deferred to later dates if the repair is cut short for any reason. This process requires dedication from the Planning personnel and management.<br>The Planning Section must be separated from maintenance so that planning can exclusively concentrate on planning activities. However, the Planning Office must be near the Mechanized Workshop.<br>The current situation at the mine creates a barrier as the two Sections are far apart from each other. Having a Maintenance Planning Office near the Mechanized Workshop will be beneficial to the Department as this will help the Planning staff to have easy access to maintenance personnel and documents. This will equally allow for collecting and completing all necessary maintenance documentation in time and according to schedule.<br>The Mining Department at Mega Mine is very flexible and supports planned maintenance activities by providing machines for maintenance on time and strictly follows the planned maintenance schedule. This should give the maintenance department adequate time to carry out quality maintenance on equipment.<br>The time maintenance personnel take to carry out maintenance can be minimized by introducing Maintenance Team Leaders (in other organizations they are called Senior Artisans or Crew Leaders) for each maintenance group. The Team leader should ensure that all maintenance parts are available at least a day before maintenance. If maintenance exceeds the planned time, the Team Leader should give a report in writing to the Foreman who should submit this report to the Superintendent for further action. Thus, a culture of time management and accountability should be cultivated.<br>Additionally, the department should introduce a store or steel cages where spares should be kept prior to the maintenance day. The Planning Office, through a Materials Coordinator, should draw materials for equipment scheduled for planned maintenance at least a day or two before maintenance. These parts should be kept in labeled spaces within the workshop area to avoid Technicians moving to and from stores looking for parts on the shutdown day.<br>Maintenance Planning should not be considered as a dispatching section, parts expediter, or a mere clerical Section. |

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 04, April-2025

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| | This is a complete waste of resources. The Maintenance Planner should have an immense potential influence on maintenance efficiency. The actions from the Planning Section should have more impact than any individual line supervisor.<br>When the Planning Section is formed, it is important to ensure that Planning does not report to Senior Management, but to Line Management. Following the Mega Mine Engineering Structure, Planning must report to the Mechanized Equipment Superintendent.<br>The implementation of an effective Planning Section with a specific structure, reporting and accountability will eradicate the differences between Planning and the Maintenance personnel as areas of responsibility will be drawn up. |
| Summary | The implementation of a maintenance planning regime that includes complete and accurate machine backlog will significantly improve the accuracy of maintenance schedules and productivity of maintenance generally.<br>Additionally, scheduling in isolation of production always leads to conflict – a planning meeting with production before finalizing and sign off on the weekly schedule will ensure sensitivity to production requirements within the caveat that production priorities do not override the requirement to ensure safe equipment.<br>When scheduling is completed in isolation of the stores function, there is usually no guarantee that parts and materials will be available for scheduled work – this leads to putting pressure on the schedule and the planners preparing the schedule. |
| Element – Equipment Performance Reports and History | |
| Purpose | The purpose of this element is to clearly define the requirements for data recording and information storage to maintain a current and accurate history of each asset, work location and personnel as well as work management generally in accordance with legal, regulatory and organizational requirements. |
| Background | No reconciled performance reports are generated at the mine, each individual Foreman only documents the availability figures of machines. This is then submitted to the Planning Office at the end of each month. No supporting data is assigned to these figures. The requirement for recording and reporting data is largely informal at the mine with varied details included on completed service sheets and other forms of inspections. The month-end report does not highlight any achievements nor challenges faced by the Section; the report only provides equipment availability figures. Additionally, no machine history data is recorded.<br>Accurate history of Assets, Location, People and Management processes are critical for corporate memory and to enable evidence-based verification of actual and forecast business performance / compliance. The scanty available machine history at Mega Mine is largely unstructured, consisting of electronic records stored by individual users on a common hard drive and hardcopy documents in various offices and archive locations. This condition limits the ability to locate and retrieve information when required. |
| Mitigation | The Department needs to examine the maintenance systems being used at the mine. This should involve examining the equipment, procedures and pinpointing areas needing improvement. This assessment should include the following:<br>i. Conduct an asset inventory<br>ii. Perform a criticality assessment<br>iii. Define Key Performance Indicators (KPIs)<br>iv. Identify essential maintenance tasks<br>v. Establish metrics for task scheduling<br>Once this is complete and agreed upon, a document (strategy) must be developed to give guidelines to all Planning and Maintenance personnel. |
| Summary | Corporate memory is a valuable organizational asset and critical for recognizing risk. Accurate records not only document the history of the assets and the project, but such records also develop the corporate memory of the organization enabling evidence-based decision making and evidence-based verification of business performance / compliance. |
| Element – Maintenance Strategy | |
| Purpose | The purpose of this element is to clearly define the requirements for developing a maintenance strategy. The element further explains the key steps and the fundamentals of developing a successful maintenance strategy. |
| Background | A maintenance strategy is a structured approach to managing assets and equipment to ensure reliability, minimize downtime, and optimize maintenance costs. It serves as a comprehensive blueprint for organizations to maintain operational efficiency while controlling expenditures. Key aspects include systematic planning, execution, and monitoring of maintenance activities to enhance performance and longevity of critical assets. Nevertheless, the Mega Mine Maintenance Section operates without any formal written strategy.<br>The maintenance strategy at the mine is a mere verbal traditional strategy which only emphasizes weekly planned maintenance. This traditional approach to maintenance strategy neglects general repairs / maintenance including defects, associated downtime, support systems and execution processes that have a high impact on machine availability, high impact on machine reliability and account for approximately 60% of maintenance costs. In addition, downtime associated with general repairs and maintenance related activities is often neglected in production planning and the performance measures to assess the impact are not in place. |
| Mitigation | The Department should develop strategies which should assist in standardizing activities and ensuring that all employees understand the requirements of the maintenance regime. The following will help the Department to develop |

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| | an effective maintenance strategy:<br>i. Define Maintenance Goals: Define the goals to unlock that type of synchronization as it spells out precisely what needs to be done, by when, and how.<br>ii. Create an Inventory of Assets: This should involve systematically documenting and cataloging every piece of equipment that requires regular upkeep.<br>iii. Conduct a Risk Assessment: This should involve identifying, evaluating, and analyzing the likelihood and consequences of potential maintenance-related hazards such as equipment failures, safety issues, and operational disruptions.<br>iv. Plan the Type of Maintenance Needed: From the risk assessment conducted, The Department should come up with specific maintenance strategies and actions required to keep each asset functioning optimally. This should include the type of maintenance required, the order in which maintenance tasks should be executed, the frequency of maintenance which should be based on intervals or any other form of metrics and the duration of downtime required for maintenance. Planning this out in advance will help define the scope of upkeep needs, which is necessary to identify the resources such as labor, materials, and budget needed to get the job done right.<br>v. Plan the Needed Resources: Resources entail labor, tools, equipment, spare parts, components, and information like technical documentation and work instructions, all essential for effective maintenance execution. Strategic planning during this step ensures that all necessary resources are always readily available, reducing the time an asset is out of operation and boosting operational efficiency.<br>vi. Calculate the Budget for Maintenance Tasks: Generating a thorough budget will help the Department allocate resources more strategically, ensuring that there is enough money to cover all regular maintenance activities, unexpected repairs, and upgrades effectively without compromising equipment performance. It will provide a clear framework for expenditure, essentially protecting the Department/company from situations of overspend on specific areas or equipment and then have no money left to cover the rest of the assets.<br>vii. Develop Standard Operating Procedures: These are detailed, written sets of step-by-step instructions on completing maintenance tasks and procedures safely, efficiently, and consistently. This is critical for maintaining the efficiency of operations, as Safe Operating Procedures ensure all processes are carried out the same way, regardless of who performs them. It eliminates a lot of guesswork, confusion, and time spent figuring out everybody's responsibilities. This increases productivity and reduces unnecessary downtime. |
| Summary | Without a clear maintenance strategy in place, there is a risk of non-compliance with regulatory agencies, extremely high labor costs, in addition to the loss of production and subsequent revenue if equipment fails stochastically. Additionally, there's a safety risk in terms of incidents and accidents, not to mention the massive environmental impact if there were spills or release of harmful materials. Following an effective maintenance strategy is a vital component of running any profitable business efficiently. Having a clear strategy in place unlocks the ability to anticipate and plan for any maintenance requirements, which present a multitude of benefits to the company as a result. |
| Element – Computerized Maintenance Management System | |
| Purpose | The purpose of this element is to highlight the importance of a Computerized Maintenance Management System. The section further explains the major benefits of this system which include helping the organization to plan, monitor, report, and optimize maintenance activities. The system helps to easily track work orders, maintain assets, and schedule maintenance accordingly. |
| Background | The Mechanized Section uses a CMMS which is more of an accounting system and does not provide the necessary access for maintenance data. |
| Mitigation | Before purchasing the CMMS package, the mine should conduct a needs analysis which should highlight the current maintenance challenges and what the mine would like to get from the system. The following should be considered:<br>i. Needs Analysis: Assess the system and determine if it can provide all the maintenance needs required by the mines. This should include whether the system can produce preferred reports, track equipment life, track equipment performance, calculating various maintenance Key Performance Indicators etc.<br>ii. Easy of use: The software must be easy to learn so that it can be utilized by a large workforce with minimal time lost to training.<br>iii. Technical Support: The CMMS service provider must be available to support the system from initial installation, training maintenance personnel on how to use the system and any other system refinement which may be required.<br>iv. Integration: The CMMS must be able to integrate with other existing technology on the mine, such as sharing asset performance and usage of information or staff records as well as being able to merge with the supply and stores system. |

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| | v. Price: One of the critical factors to consider should be the price of the system and any payment programs associated with it. The mine must consider whether the potential savings are worth the cost of the CMMS software selected.<br>vi. Knowledge of the Provider: The provider must have adequate knowledge of maintenance and planning in the area where the system is required. |
| Summary | An effective CMM will assist in minimizing equipment downtime. By performing timely and regular preventive and predictive maintenance, the Maintenance Section can reduce the chance of an unexpected failure, thus, removing an asset from unnecessary work processes which are counterproductive and time wasting. On the other hand, the CMMS can be used to order supplies automatically when inventory gets low, with enough lead time to receive new stock before running out of old stock. The system can also prevent ordering too much inventory and avoid costs associated with waiting for needed items or repairs. |

Note that not all observed elements have been discussed in this section, only those which were identified as a major risk to the maintenance regime at Mega Mine have been considered.

## CONCLUSION

The main objective of the study is to identify challenges and shortfalls in the maintenance management system of the Underground Drill Rigs, Loaders and Dump Trucks at Mega Mine and to propose improvement measures that could assist enhance maintenance activities. Hence, the study sought to investigate and evaluate how Maintenance Planning, Tyre Management, Lubrication Management, Machine Systems Interlock Management and the interaction between Maintenance Planning and Maintenance (Workshop personnel) affects the performance of the three key production equipment. The other area reviewed is the availability and usage of a fit for purpose Computerized Maintenance Management System.

The most significant finding to emerge from this study is that the Mega Mine Maintenance Department has not carried out any maintenance audit to determine the maintenance needs to formulate a Maintenance Strategy. This has therefore caused the Department not to have a streamlined maintenance system where maintenance activities are carried out in an organized manner. Maintenance personnel focus more on reactive maintenance. This is mainly due to a lack of a formalized maintenance system. Planning is seen to be more responsive to breakdown events and not planning. The delay disruption effect of not planning is just as significant for all maintenance interactions. The absence of formal planning processes and routines has a significant impact on the quality of maintenance carried out and the productivity of the maintenance crews. It is difficult to provide the right tools, the right parts and the right time to the maintainers because work is not adequately planned.

## 7.0 RECOMMENDATIONS

To identify shortfalls and challenges in the maintenance of Drill Rigs, Loaders and Dump Trucks at Mega Mine, an Ethnological study was conducted. Therefore, the findings of the study have implications for both theory and practice.

### 7.1 Practical Recommendations

The practical recommendations relate to how Mega Mine Maintenance Management can address the identified maintenance factors affecting Underground Drill Rigs, Loaders and Dump Trucks.

The study, therefore, recommends that Management at Mega Mine Should assess the equipment maintenance needs in line with the elements provided and any other areas the maintenance Department finds lacking. From this, maintenance objectives and strategies should be developed to align the Department personnel with the mine requirements.

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Theoretical Recommendations

The theoretical recommendations of this study arise from the limitations that the study faced, their implications and hence suggestions of areas for future study. Through the search of literature and on-site observations, other areas of interest arose, however, these areas were not handled conclusively in this study, hence, the recommendation for further studies.

Limitations

Although this study considers the maintenance shortfall as the major factor affecting the maintenance Organization of Drill Rigs, Loaders, and Dump Trucks at Mega Mine, it falls short of analyzing areas such as the production and cost implications arising from maintenance shortfalls. Therefore, future studies should consider empirically analyzing the impact of equipment reliability on the company bottom line.

This study is based on a single mine, Mega Mine, therefore, findings from this study may not be generalizable to other organizations.

Areas of Further Research

Most studies on underground mechanized equipment focus on the availability and utilization of underground primary equipment. This study, therefore, contributes to the already existing knowledge about the performance of underground mechanized equipment. In this regard, there is a need to carry out more empirical studies to test how other factors such as underground environmental conditions, operator practice, tramming distance and availability of maintenance parts affect reliability of equipment.

Finally, the gaps identified in this study can be used as journal manuscripts for further literature review to readers and researchers who may be pursuing a similar study.

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