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# Investigating the Cause of Premature Tyre Failure of Open Pit Mine Dump Trucks: A Case of ABC Mine, Northeast Africa

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***Abstract:*** **Globally, earthmoving equipment is significant for the mine production system to ensure continuous flow of ground. This equipment is capital intensive and mining organizations face challenges in reducing operational cost, capital cost and maintaining high production capacities. As such, high equipment availability, safety of personnel and equipment, maintainability and controllable reliability become an important aspect. Several maintenance strategies have been developed, backed up by various models and frameworks to help minimize equipment failure as unplanned equipment downtime has a triple cost implication on the organization. These costs being, production cost in not meeting the output target, maintenance cost; the more breakdowns experienced, the more parts will be required to repair broken down equipment as well as maintenance labor cost which usually arises from unplanned work. Finally, fixed cost associated with mining operations such as power. To ensure that equipment downtime is minimized, routine equipment maintenance has been given priority, however, tyre performance has received less attention in comparison with other equipment components such as engines, transmissions, gearboxes and final drives. 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. ABC Mine (not the real name) experienced a number of premature failure of Dump Truck tyres during the period January 2019 to April 2020 and the main cause of failure was not adequately established, though the failure modes data was collected and recorded through the Planning Section. Further, the Mine Management attributed these failures to poor operator practices and the harsh environmental conditions at the Mine. The aim of this study is therefore, to investigate the actual cause of the numerous tyre failures at ABC Mine. Reliability and Maintainability characteristics; Meantime Between Failure (MTBF) and Meantime To Repair (MTTR) associated with tyre performance were reviewed in order to show the effect of tyre downtime on productivity. Data collection was through document review from planning office, Vehicle Information Management System (VIMS), participant observation and through calculation of operating parameters such as TKPH. Tables and graphs were used to present data trends and their characteristics. The study concluded that, the numerous premature failure of the Truck tyres at ABC Mine during the stated period was as a result of the wrong specification of the tyre. The TKPH of the tyre used was lower than the real site TKPH, hence, failing the condition: Tyre TKPH ≥ Real Site TKPH. Though the maintenance side of the tyre management system and the load and haul management system contributed to the low tyre life due to their ineffectiveness, TKPH of the tyre had the greatest impact on tyre life.**

**Keywords: Tonne Kilometer Per Hour (TKPH), Pyrolysis, Lateral Acceleration, Tyre, Payload, Scuffing, Maintenance.**

## 1. INTRODUCTION

In the mining industry, maintaining high level of equipment reliability, utilization, production and quality is essential to the financial performance of the organization. Effective maintenance plays a vital role in productive capacity and equipment capability, therefore, opportunities must always be sought to improve equipment reliability in order to minimize maintenance cost and increase productivity. Dump Trucks are one of the most important equipment in the

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hauling of ground and their tyres constitute significantly to the machine running cost. Morad, Mohamad and Sattarvand (2014) indicated that, loading and hauling equipment is considered as the most valuable assets of an open pit mine which correspond to the vast amount of capital invested and that maintenance of these vehicles is critical to the movement of ground. Additionally, Yadav, Gupta and Kumar (2020) showed that, Dump Trucks are one of the most widely capital intensive heavy duty equipment used in the mining industry and that continuous monitoring of the equipment's performance is necessary for a mining system. They further commented that, it is necessary to have a well-defined performance measure (PM) to monitor performance. In line with this philosophical ideology, there has been a lot of attention on the maintenance of mining equipment, however, tyres have not received the attention they deserve like other equipment components such as engines, transmissions, gearboxes and final drives. 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. In many mining operations, there has been always a battle between the maintenance and mining department as to who should be responsible for tyre downtime. This approach has caused tyre downtime to be a "silent" equipment reliability attribute. The crush between the two giants has led to certain operations reporting two separate sets of availability figures, mining availability; which takes into account tyre downtime and engineering availability where tyre downtime is excluded. Jan Trouw, former General Manager for Chibuluma Copper Mine in Zambia once said, tyre downtime is a mining responsibility as miners operate the equipment, they need to clean their work areas as well as roadways, however, maintenance personnel must not go into hiding, they have the responsibility to technically manage the tyres and educate the poor miner.

ABC Mine is an open pit operation and runs different types of mining equipment such as Dozers, Excavators, Dump Trucks and other ancillary equipment. In terms of production Dump Trucks, the mine operated thirty (30) CAT 775 and eight (8) CAT789B. During the period January 2019 to April 2020 (the time of the study) the nine experienced a high failure rate of the CAT789B Dump Truck tyres. The tyre life was below the mine expectation and the main cause of the low tyre life was not adequately investigated for the mine management to make informed decisions, though management concluded that, the failures were as a result of poor operator practices and the harsh environmental conditions. Nyaaba (2017) commented that, Truck haulage is a primary material transport system for most surface mining operations and constitutes a significant component of the overall production costs. At ABC Mine, the tyre cot constituted 20 to 25% of the total HME maintenance cost.

ABC Mine through various consultants in the past has used several cutting-edge rubber material testing techniques, computer simulations, mathematical models, rubber fatigue analysis and other methodologies such as finite element simulations to try and extend tyre life at the mine, never the less, this new challenge was unique. Thus, this research seeks to identify the main cause of the numerous CAT789 Dump Truck premature tyre failure at the mine.

**Background**

As competitive pressure keeps on mounting on the mining industry to be more efficient and effective, most mining organizations have invested significantly in various maintenance strategies in order to avoid spiking costs arising from unplanned equipment downtime. Tyres are one of the major mining cost drivers as well a one of the major components on the machine, hence, they need to be managed effectively. Wang, Al-Qadi and Stanciulescu (2001) commented that, Dump Truck tyres are critical components of haul trucks used in surface mining in that they cushion Trucks against the rigorous terrains, control stability, generate maneuvering forces and provide safety during operation. As stated, ABC Mine operated thirty (30) CAT 775 and eight (8) CAT789B. For the eight CAT789B Dump Trucks, the mine was using various brands of tyres; Michelin, Bridgestone, Good Year, Dunlop and Titan. The tyre size used was 40.00R57 and Michelin recommended a 40.00R57 Michelin XDR3 MB4 E4R. However, the recommended tyre could not be found at the market when the mine wanted to purchase it, therefore, an alternative was sought.

During the 2019/2020 financial period, the mine was expected to mine from Phase 6, however, due to some technical issues, the mining plan was changed to Phase 7 with a longer hauling distance. With the looming global tyre shortage, the mine opted to purchase 150 tyre of a similar brand from a single supplier at $28,000.00 each (this figure does not include taxes and transportation cost). Global tyre shortage is not unusual, it has been experienced several times. Following the 2008-2009 slump in commodity prices, demand for truck tyres far exceeded the supply capacity. The secondary market price of a 40.00R57 tyre increased by 68% in a six-month period. According to Cutler (2012), it was estimated that around 2012, most tyre suppliers had about 25–30% undersupply in the market for three years running. The demand had surpassed supply with the tyre shortage crisis pushing the price up by as much as 425% since 2009.

The mine however, experienced a high failure rate of tyres from the purchased consignment. The tyre life was continuously below the mine expectation and the main cause of the low tyre life was not adequately investigated for the mine management to make informed decisions. The mine expected to get an average life of 5000 hours from a tyre, however, all the 140 tyres used on the equipment during the period under review only achieved an average life of 1100 hours. Only 105 tyres were accurately recorded out of the 140 failed tyres. This condition may not be unique to ABC Mine alone, from the study conducted by Kagogo (2012) at Rossing Uranium Mine in Namibia, it was established that between 2010 and 2012, the tyre performance for Komatsu Haulpak 730E 2000 HP haul trucks was below budget. The mine had experienced premature failures in 49% of the tyres, with cut separation being the most common cause. The study conducted by Mars and Fatemi (2004), concluded that, the number of tyre failures due to mechanical fatigue accounted for 20% of working tyres with 75–96% of average service life. At ABC Mine, various failure modes were observed, however, the main cause of failure was not fully explored, though the mine management attributed the failures to poor road maintenance and driving practices such as over-speeding on bends.

Many operations have gone through and are still going through massive Truck tyre premature failure, despite several extensive practical measure and innovative computer based programs, a lasting solution to reduce premature failure of heavy mining equipment tyres may only be achieved through concerted fundamental and applied research initiatives by the mining organizations.

Most of the mining companies have taken a traditional way of only investing and recording the failure modes of tyres, these being sidewall cut, penetration, crown failure, separation, shoulder cut, belt cut, abrasion and normal wear. They mitigate the physical observable causes of failure such as bad roads and housekeeping. However, contributing factors such as temperature, speed, angles of the road, curves and inflation of tyres are rarely considered and remain silent.

A mining Truck Tyre (hyperelastic mechanical structure capable of supporting vehicle loads by its contained air pressure) is a complex mechanical structure which operates on varying multi-physical phenomena. The tyre is constructed to operate in off-road conditions and meant to carry a specified amount of load. Though various environmental conditions cause tyres to fail before their predicted time, these tyre are intended to resist some conditions to a certain degree unless other critical factors are overruled or ignored.

## 2. METHODOLOGY/DATA COLLECTION

The overall objective of the study was to identify the cause of the premature failure of the CAT789B Truck Tyres at ABC Mine for the period January 2019 to April 2020. The study was underpinned on a pragmatic view point and applied a multi-methods approach. Data were collected from performance reports, participant observation, subject matter expert views (key informants) and vehicle VIMS. Qualitative data was analyzed using the inductive process of building from the data to broad themes and then to a generalized model or theory. Quantitative data was analyzed by using descriptive statistics where graphs and tables were used to present the data. A site severity survey was conducted to gather data relevant to the study such as calculation of the site specific Tonne-Kilometer Per Hour (TKPH). TKPH is the rating for a tyre specification representing load carrying capacity in relation to heat generation. In other words, it is a function of the load and distance (Kilometers or Miles) covered per hour at an ambient temperature of $38^{o}$ C.

### *1. Document Review*

The data used in this section were obtained from HME Planning office where all tyre management data was assembled and analyzed for decision making. The general information included:

i. Machine type – CAT789B Dump Truck

ii. Truck Capacity – 177tonnes

iii. Tyre size – 40.00R57

iv. Tyres per machine – 6

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v. Tyre brand used at the mine – Michelin, Dunlop, Good Year, Bridgestone and Titan. Only one batch of Titan tyres was used.

The tyre performance for the six (6) CAT 789B Dump Trucks which were in service for the period January 2019 to April 2020 was observed, two Trucks were decommissioned due to poor reliability which resulted into high maintenance cost. Downtime arising from tyre failures and the failure modes were recorded. Figure 1 shows the number of tyres replaced per month during the period under review.

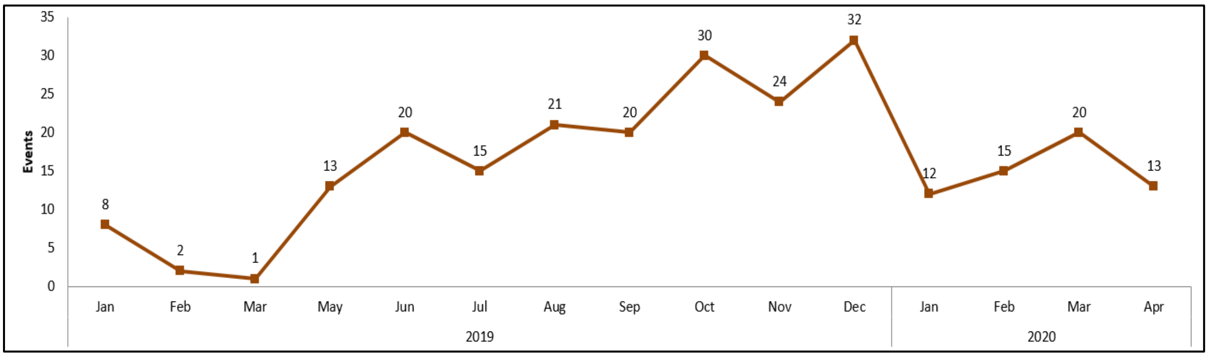


**Figure 1: Tyres Replaced Per Month**

The data in figure 1 shows the number of tyres replaced per month, the average tyre life for all failed tyres was 1100 hours as opposed to the projected 5000 hours. Figure 2 shows the machine monthly downtime due to tyre failures.

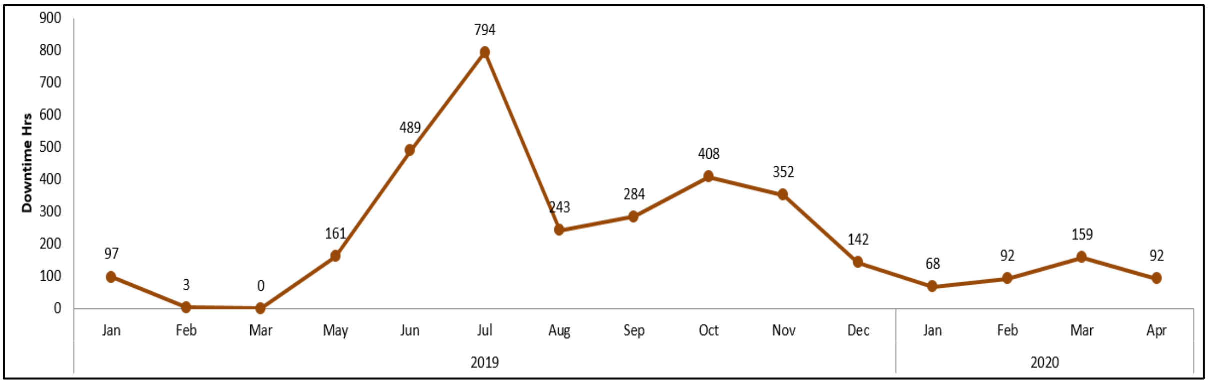


**Figure 2: Tyre Downtime**

The data in Figure 2 illustrates monthly tyre downtime for the failed tyres, June and July 2019 showed the highest downtime. The explanation to the extended downtime was that, this tyre size was new on the mine and both skills and tools were not adequate. Figure 3 shows tyre downtime against failure events.

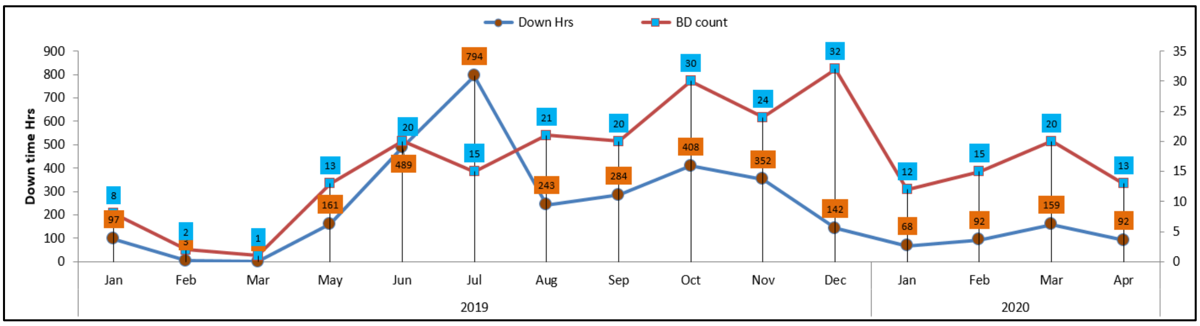


**Figure 3: Downtime Vs Event Frequency**

The commissioning of these machines started in January 2019 and major tyre failures began occurring in May 2019. Figure 4 shows the time the Trucks were commissioned.

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| DT40 | DT41 | DT42 | DT43 | DT44 | DT45 | DT46 | DT47 |
|---|---|---|---|---|---|---|---|
| April 2019 | Jan 2019 | Jan 2019 | Jan 2019 | April 2019 | Jan 2019 | Jan 2019 | Jan 2019 |

**Figure 4: Machine Commissioning**

Figure 4 shows when each machine was commissioned, however, DT43 and 47 were decommissioned in April 2019 due to low reliability and increasing maintenance cost right from commissioning.

The tyre failure mode and frequency were recorded and this data was reviewed and rearranged as shown in Figure 5.

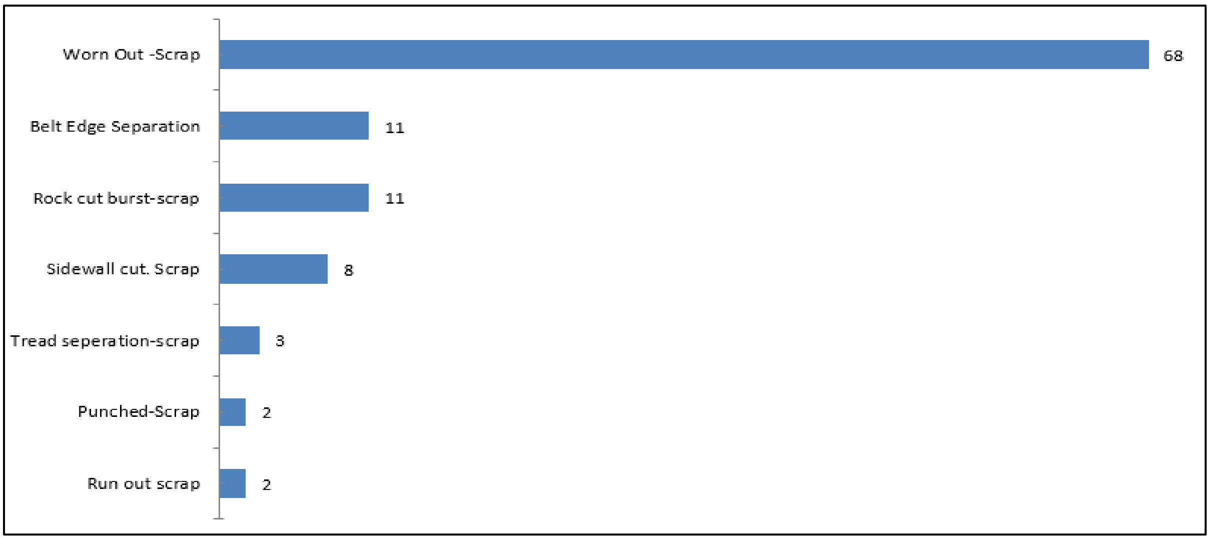


**Figure 5: Tyre Failure Mode**

Figure 5 shows the failure mode and occurrence, however, all the tyres during the period under review failed before the anticipated time. The average life for the tyres was 1100 hours whereas the projected life was 5000 hours. This implies only 22% of the tyre was used.

Though the life cycle of the tyres was low, the reliability of the equipment from commissioning to the time of the study was below budget due to other faults on the equipment, this downtime further released the workload from the tyres. Figure 6 shows the availability of the equipment during the period under observation.

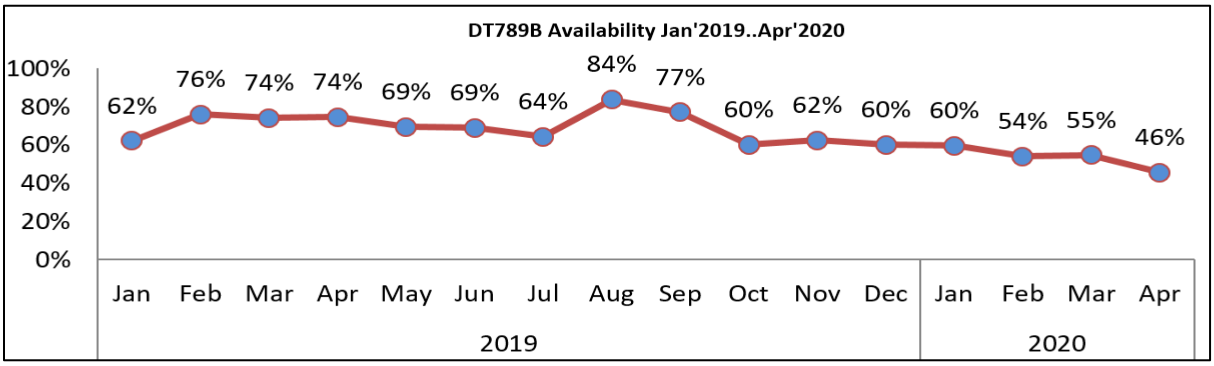


**Figure 6: Equipment Availability**

Generally, the machine reliability was low and this resulted into low utilization. The equipment had a number of other mechanical and electrical failures throughout the year from commissioning. Figure 7 shows other machine downtime causes.

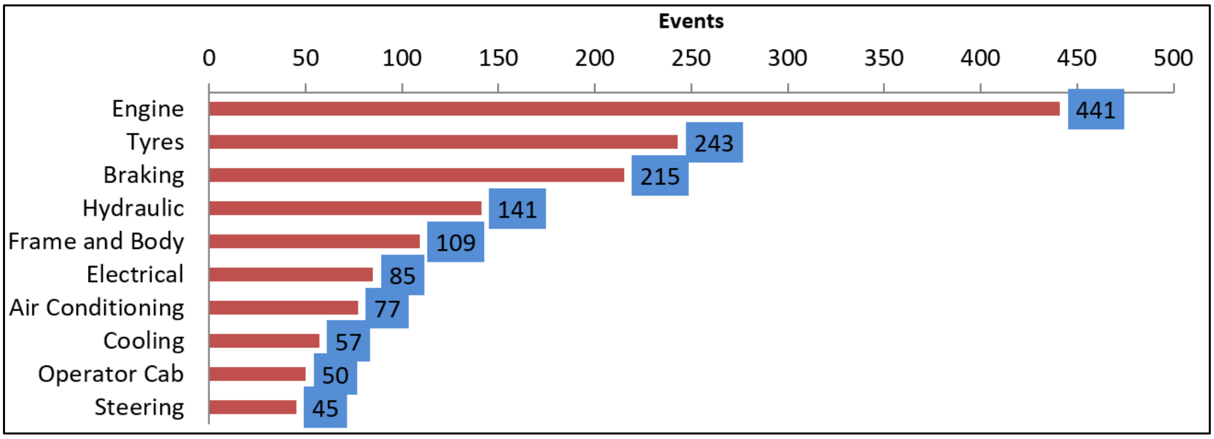


**Figure 7: Machine Component Failure Mode**

As seen from Figure 7, the equipment had several other failures that made the equipment unreliable and to operate less hours than planned. Figure 8 shows the monthly cumulative hours done.

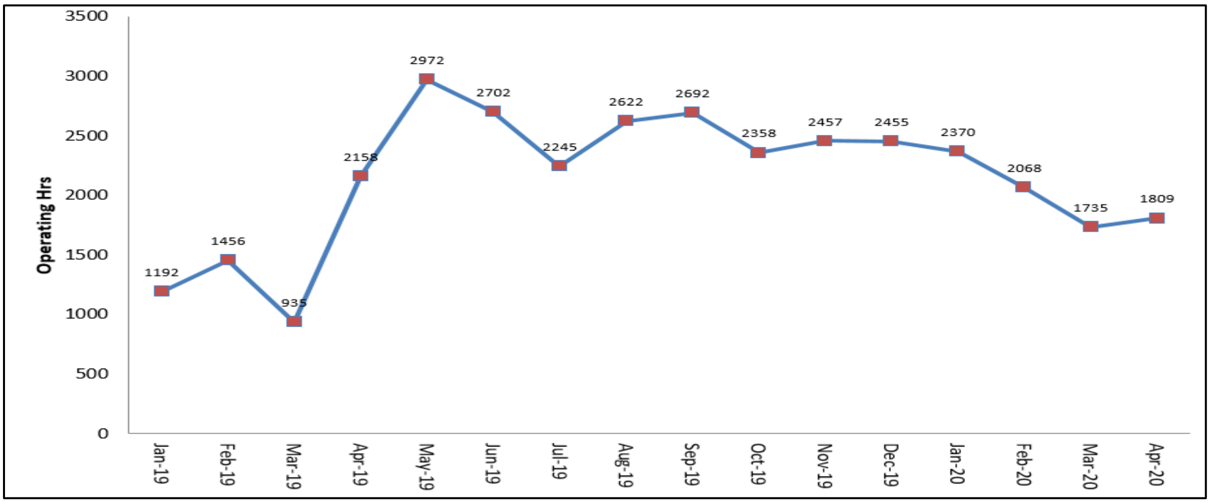


**Figure 8: Dump Trucks Operated Hours.**

The machines were expected to operate at 85% availability, however, the equipment could not meet this target due to breakdowns. Figure 9 shows the reliability measure of Meantime Between Failure (MTBF).

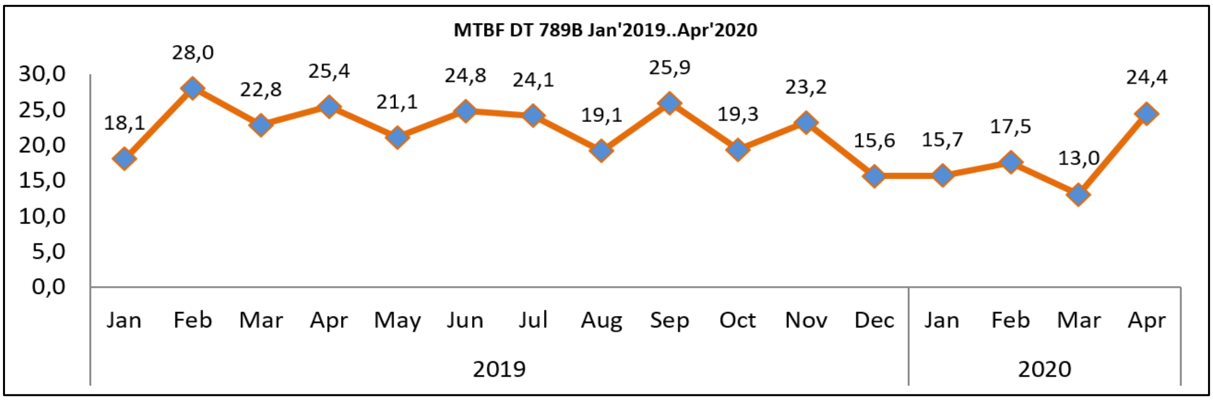


**Figure 9: Meantime Between Failure**

Though the Meantime Between Failure kept on declining, the tyre downtime did not take a declining trend, the failure rate was still high.

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### *2. Participative Observation (Site Severity Survey)*

A sight severity survey was conducted to ascertain the condition of the environment from which the Dump Trucks operated. An audit of the tyre workshop, storage areas and the pit was also conducted. In order to ensure that all the required data were adequately collected, a checklist was developed. Figure 10 shows the checklist which was used to collect data.

| Item | Description | Available | | Comments |
|---|---|---|---|---|
| | PPE | Yes | No | |
| | Compressor | x | | |
| | Cages | x | | |
| | Chock blocks | x | | |
| | Isolation tags | x | | |
| | Pressure gauges | x | | |
| | Gas testers | | x | |
| | Tyre handler | x | | |
| | Vehicle stands | x | | |
| | Signage | x | | Not to standard |
| | Storage | | x | Not segregated according to:<br>• New – mounted<br>• New – not mounted<br>• Partly worn – usually mounted<br>• Remanufactured (re-tread)<br>• Worn out – Kept for matching<br>• Worn out – For inspection<br>Tyres are stored outside exposed to various environmental conditions |
| | Water | x | | |
| | Component store | | x | Small one exists, but not adequate for the size of fleet. |
| | Road Maintenance Crew | x | | |
| | Speed Monitoring | | x | |
| | Specialised Grader Operator Training | | x | |
| | Tyre Pressure Monitoring | | x | Done at random, not consistent |
| | TKPH Monitoring | | x | |
| | Tyre Awareness Campaign | | x | |
| | Tyre Life Monitoring and Feedback | x | | Though not effective |
| | Maintenance Personnel Training on Tyres | | x | Partially done. |
| | Road Condition Monitoring | | x | |

**Figure 10: Audit Checklist**

There was no physical tyre workshop at the mine, tyres were changed from an open space in front of the Dump Truck workshop. The signage was not to standard as there was only signs displaying the kind of PPE required within the workshop area, there was no sign related to tyres or tyre safety.

The storage of tyres was not adequate, the tyres were placed in an open space exposed to various environmental conditions such as heat from the sun and water. Stands and chock blocks were of a correct design and adequate in number and all personnel working on tyres had correct PPE. Additionally, the mine had a universal tyre handler which was suitable for all heavy duty tyres on the mine. Figure 11 shows the tyre worksite area.

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**Figure 11: Tyre Work Area and Storage Yard**

Further, the tyres were not segregated according to their condition, there were only two areas of new tyres and failed or worn-out tyres. Figure 12 shows the tyre and components storage areas. These are assembled, worn-out and damaged tyres as well as tyre components.

**Figure 12: Tyre and Components Storage Area**

A pit audit was conducted and the following observations were made:

***Loading area***

i. Spillage – loose gravel ranging from 5mm to 35mm

ii. Undulation – active undulated ground

iii. Payload distribution – load along center of the machine and concentrated to the front of the machine

iv. Loading point layout – moderately wide loading area. However, it requires the machine to reverse and maneuver

v. Surface condition – dry

vi. Size of surface material – aggregate 5 – 50mm

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Figure 13 shows the loading area with a Dump Truck being loaded and a Loaded Truck heading for the tipping point.

**Figure 13: Truck Loading**

***Haul Road***

i. Width – the majority of the roads were wide with few tight corners
ii. Spillage – noted, moderate to high risk of tyre cuts and aggression
iii. Undulation – low to moderate
iv. Sharp turns – two (2) sharp turns were observed on the road
v. Water – not significant, reasonably dry
vi. Size of surface material 5 – 50mm

Figure 14 shows the condition of the roadways.

**Figure 14: Road condition**

The two tight turns were observed near the two dumping points, however, operators were encouraged to reduce speed as they approached these two areas. Figure 15 shows the location of the two sharp turns.

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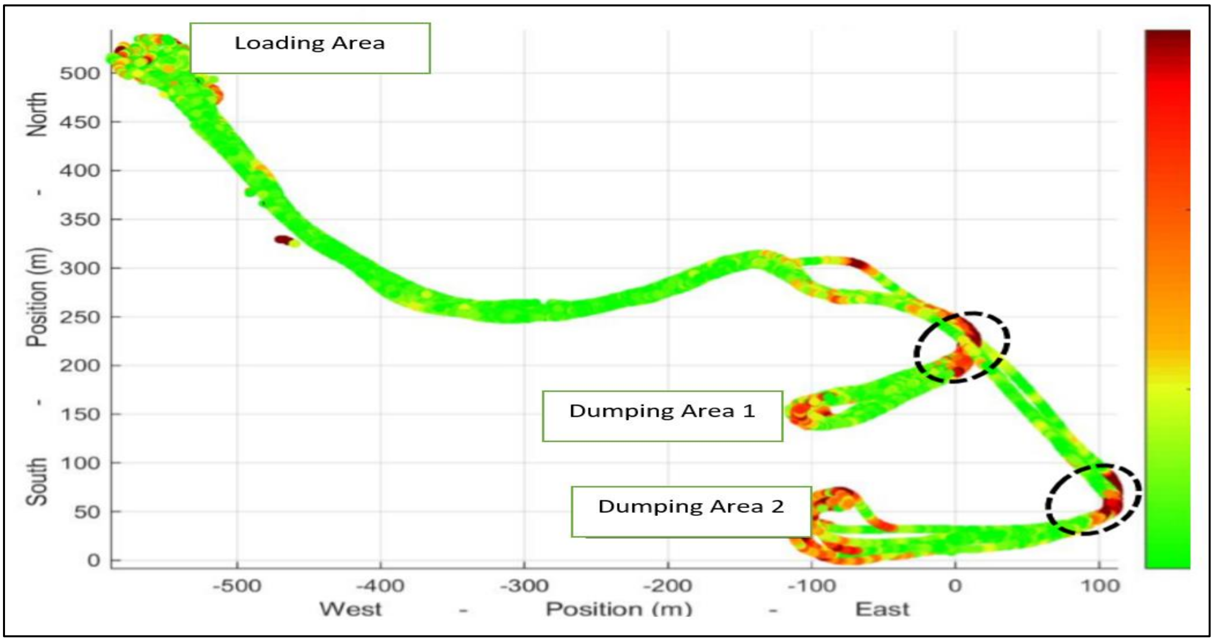


**Figure 15: Haulage Route**

***Unloading Area***

i. Spillage – low to moderate

ii. Undulation – frequent undulation, hard compacted surface

iii. Water – dry surface

Figure 16 shows a loaded Truck around the unloading area.

**Figure 16: Dumping Area**

Lateral acceleration was observed in a number of areas more especially around the turns to the dumping area. Lateral acceleration is the force that 'throws' a moving vehicle sideways during a turn. Table 1 shows the curve radius against the Truck speed along the route shown in Figure 15.

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**Table 1: Radius Versus Speed**

| Curve Radius | Actual Speed | Recommended Speed |
|---|---|---|
| 15 | 14.2 | 8 |
| 25 | 13.4 | 10 |
| 50 | 15.9 | 15 |

The route did not have major slopes, though in certain areas the maximum downhill reached 10%. Figure 17 shows the deterioration of a tyre due to slope effect.

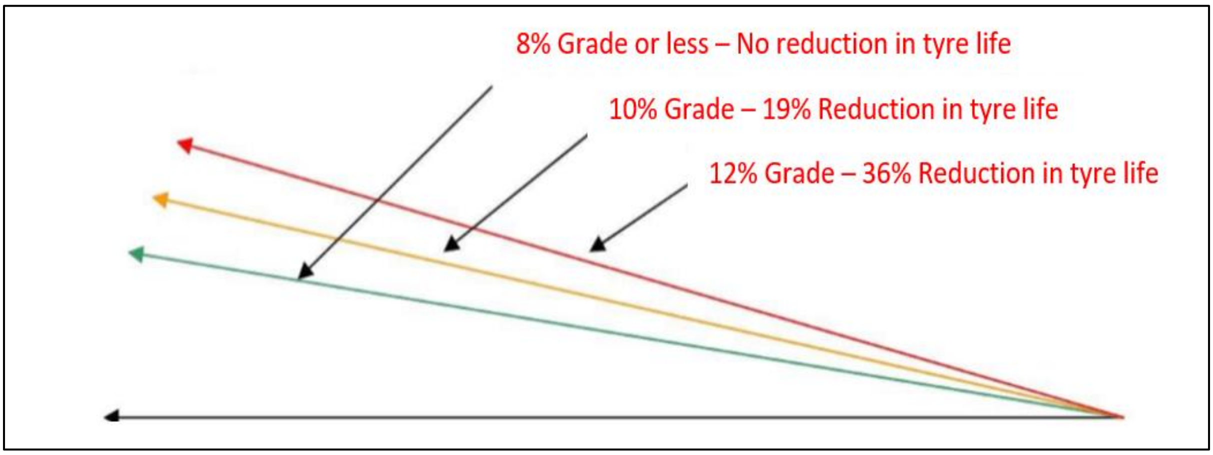


**Figure 17: Tyre Wear Rate**

The condition of tyres, both on the machine and dismounted were observed to determine the nature of failure and the possible failure cause. Figure 18 shows the condition of two separate tyres on a Truck.

**Figure 18: Tyres on a Dump Truck**

The cracks were not sustained from any sharp object, but developed while the machine was in service. This was common to all CAT789B Trucks investigated and a lot of rubber pieces from tyres were noted along the haulage route. Figure 19 shows some of the failed tyres with respective operated hours.

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**Figure 19: Tyres Failure Modes**

Figure 19 shows some of the failure modes observed, a number of tyres failed in a similar ways at low operating hours. Three (3) blow outs were experienced with no injury to personnel, however, from two incidents, nearby equipment was damaged, a Dozer and an Excavator, both lost side windows.

## 3. COMMON CAUSES OF TYRE DAMAGE

In an open pit mine, tyre fatigue life is influenced by various controllable and uncontrollable factors which include thermomechanical loading history, irregularities in rubber formulations, chemical reactions, abuse, environmental factors, and effects due to the dissipative nature of the rubber materials:

*Thermo-Effects (Heat)*

Within the rubber of a tyre, heat is generated duet to hysteretic losses as the tyre (rubber) goes through cyclical flexing at ground contact pitch. Tyre heat is generated faster than it is dissipated, hence building up within the tyre over time. As such, heavy loads at high speed become harmful to the structural integrity of the elastomeric structure of the tyre and this leads to the science of tyre rubber fatigue degradation such as TKPH. Running a tyre over and above its critical rating results into a reversal of the vulcanized rubber back into the gum state and this is likely to initiate escalated wear of the tyre as the rubber is weakened. It was determined from the study conducted by Kainradl and Kaufmann (1976) that, for a given tyre construction, tyre operating temperature can be minimized only by altering its rubber viscoelastic properties and it was further established that, viscoelastic properties of the elastomers in a tyre determine the quantity of heat generated in it. This is also one reason why it is important to compare the TKPH of a tyre with that of the site before putting a tyre into active use.

It can further be indicated that, a tyre's thermomechanical fatigue is fundamentally caused by a combined thermal and mechanical service loads, therefore, speed and loading of the Truck must always be within specified limits to avoid excessive build-up of heat. It should also be noted that, a tyre thermomechanical problem is essentially a 3D rolling problem in which stresses resulting from the continuous cyclical loading of tyre materials in the footprint initiate and/or drive the growth of defects in the tyre. In big mining Trucks, tyre heat is not only generated from loading and speeding, but also from running components of the machine such as the engine, axles, transmission and torque convertor. Raised temperatures speed up chemical degradation processes in the tyre rubber compounds. Therefore, where possible, these components must be shielded with products such as aluminum blankets to minimize heat transfer to the tyres. From the study conducted by Trivisonno (1970) it was concluded that lower tyre operating temperatures can lead to increased tyre durability, hence, the need to obtain a complete temperature distribution in a tyre to ensure that the operating temperature is maintained below critical values.

Prevention is better than cure, it is usually difficult to determine the amount of heat within a tyre as the tyre size (Rubber thickness) and weight prohibits the use of experiments to determine, stress, thermal and fatigue performance. As such, measures must be taken to minimize tyre heat. It is also important to ensure that the correct tyre is used for the intended purpose, the duty determines the amount of rubber thickness used in a tyre and dispersion of heat depends on the rubber thickness as the dynamic properties of materials are responsible for their heat generation. Temperature of any material increases when the heat generated in that material exceeds the rate of dissipation. Therefore, correct rubber material thickness must be used for a specific tyre application and this can only be achieved through TKPH confirmation.

*Tyre Pyrolysis (Chemical Reaction)*

Tyre pyrolysis is a process of chemical decomposition of rubber due to heat which usually starts at $250^{\circ}C$. One of the most common forms of pyrolysis in mining tyres is through a diffusion process of organic compounds such a wood when left in a tyre. As a result of chemical decomposition, by-products such as methane, butadiene *C4H4*, and styrene $C_8\ H_8$ are formed. These products are highly flammable and with the presence of oxygen (concentration level by volume of 4.6%) can result into tyre explosion. Auto-ignition of gasses takes place at approximately $430^{\circ}C$ . Additionally, pyrolysis can be caused by Trucks or any other vehicle fitted with rubber tyres coming into contact with electrical power lines, when struck by lightning, heat applied to rims through such activities as welding, heat generated from excessive rubbing of brakes, leaving foreign materials in tyres that may decompose, external fires (e.g. engine bay fires, hydraulic fires, electric fires, grass fires in parking area), heat separation (i.e. separation of rubber layers in tyre leading to further heating from rubbing friction), overloading or over-speeding of the vehicle (e.g. exceeding its tonne kilometer per hour or TKPH load-speed rating) and running on under-inflated tyres. These initiating events can set off a chemical explosion (pyrolysis) or a diffusion initiated explosion (caused by the heating of foreign material left inside a tyre) that causes the sudden increase of internal tyre pressure, which could be up to seven times the working pressure, resulting in a catastrophic failure of the wheel assembly. It is equally important to note that, when a machine comes into contact or suspected to have come into contact with an electrical power line, the power line should be de-energized prior to the operator exiting the cab and the operator evacuated. Where a machine gets into contact with an overhead power lines, the operator shall remain in the cab and shall not touch any part of the vehicle frame until it has been confirmed that the power in the lines has been isolated. The operator shall then alight from the vehicle but not in the normal manner, he or she shall leap from the machine when close to the ground in order to ensure that there is no simultaneous contact between the person and the machine to ground. The equipment shall be barricaded and not moved for a period not less than 24 hours. If a machine is struck or suspected to have been struck by lightning, the vehicle shall be barricaded and not operated for a period not less than 24 hours.

In summary, pyrolysis is the decomposition of carbonaceous material inside a tyre. Heating of the rubber (inner liner) releases gaseous volatile organic compounds into the air chamber of the tyre. Under certain temperature, pressure and concentration conditions, this volatile mix of air and fuel can become an explosive mixture and achieve auto-ignition. Rapid spontaneous combustion typically results in large catastrophic failures with destructive outcomes. Caution must be taken in handling tyres in that, pyrolysis reaction cannot be detected and explosions can result spontaneously without warning or any obvious external visible signs that the tyre is progressing towards auto-ignition. Therefore, all necessary precautions must be taken into consideration to avoid such catastrophic failure of tyres which could lead into serious injury to personnel or equipment.

*Tyre Inflation*

The correct tyre inflation pressure settings, cold and maximum hot inflation pressures, should be determined in consultation with the tyre manufacture for a specific site application. This depends on the tyre specifications, vehicle type and other stated operating parameters.

An over-inflated tyre is stiffer and susceptible to rock impact cuts and may lose traction due to distortion in its shape. In addition, over-inflation results into uneven and rapid wear of the tread and loss of strength in the fiber reinforcements. Over-inflation further makes the tyre more rigid and less able to absorb impacts, and breaks and cuts are more likely when driving over hard and sharp objects. This condition also increases the risk of a tyre burst, particularly for already damaged or weakened tyres. At the recommended pressure, the tyre can conform to the shape of any road obstacle that it may run into, thereby reducing the magnitude of plausible cuts through the tread or sidewall. On the other hand, under-inflation increases tyre running temperature and can result into a decreased belt adhesion, which is the main cause of tread separation, heat separation caused by over work, irregular wear of the tread caused by excessive tread movement, separation caused by excessive sidewall distortion, friction and chafing caused by distortion of the bead area or slipping of the bead, and separation of plies due to high stress between plies. Where a tyre is run flat and no fire is present, but there exists the potential for explosion e.g. heat build-up due to under-inflation, the equipment shall not be operated, but shall be parked immediately and barricaded for a period of 24 hours.

*Scuffing*

Scuffing occurs to the front tyres when the tyres are incorrectly positioned when loading. During loading, if the front tyres are not positioned in the direction of exit to the loading area, the operator will pull out with tyres turned to the exit position at a very low speed. This condition places extremely high stress on the tyre lugs or treads and this results into separation of the tyre, usually from the shoulder section. The best practice while loading is to position the front tyres in the direction of exit.

*Payload (Overloading) and Loading Techniques*

Overloading of Trucks has a detrimental effect on tyre life in that extra load exponentially decreases tyre life by putting more stress on the tyre material. The stress experienced is capable of pulling the plies off position and this can cause the tyre to explode.

Caution should equally be taken while loading, loading of a Truck must be done by a recommended loader or excavator. Loading a Truck with a bigger loading equipment say, loading a CAT 775 Truck with a CAT6040 Excavator, has a major impact on tyres due to impact loading which could cause damage to the tyre rubber and plies.

The other condition to be observed while loading is skewness in loading, skew loading causes one side of the Truck to carry excessive load. This situation increases the stresses on the tyre as well as on suspension components. In severe instances, the dump body rubs against the tyre and cases further tyre damage through physical damage to both the tyre and vehicle body and propagation of temperature in the tyre through friction.

*Vehicle Speed*

Driving above the prescribed speed limit of a tyre creates excessive heat which could be detrimental to the structural integrity of the tyre material. Heat is generated due to hysteretic losses in the tyre rubber as it undergoes cyclical flexing at the ground contact patch, hence, temperature rise in the contact patch depends on tyre rolling speed. Speed exaggerates wear when negotiating bends at high speed as the tyre takes more load on the shoulder and this is likely to cause separation from the shoulder area. In short, excessive speed causes increase in the internal temperature of the tyre, fatigue and rapid tread wear.

*Tyre Matching*

The tyre pairs on the rear axle of a Truck need to match in order to ensure even wear of both tyres. When tyres are mismatched, there is usually a tendency of the load exerting pressure on the vehicle unevenly and resulting into suspension failure. Other sections of the vehicle such as the frame and center section are equally affected.

*Spillage*

Though spillage may be taken as a normal occurrence in open pit operations, the effect of running over spilled rocks could be detrimental to Truck tyres, therefore, operators need to be aware of the dangers of driving over spillage. This also includes spillage around the loading area. Loading area must always be keep free of loose rocks which may cause damage to tyres.

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*Driving onto the berms*

Sharp rocks may be hidden on the sides of berms and running over such rocks could cause serious damage to Truck tyres, as such, driving too close to the sides of the berms should be avoided.

*Roadway Conditions*

When it comes to roadway conditions, a number of factors are to be considered; the angles of the road must suit the Trucks deployed, bends must be made to accommodate specific Trucks and taking into consideration the Truck speed. The road surface must always be graded to get rid of protruding rocks which may cut the tyre treads. In road maintenance, ancillary equipment such as Dozers, Graders and Water Trucks must always be available.

Other causes of tyre failure include; defects created during the manufacturing process, defects created when the tyre was designed and damage caused during mounting of the tyre on the rim as well as during dismounting. Defects created during mounting and dismounting of the tyre assembly usually relate to bead failure, when the bead fails, the tyre can rapidly deflate, explode or the tread could separate.

In summary, there are several other factors that may contribute to tyre failure, therefore, it is important to have dedicated road maintenance team to look after the roads and loading areas as well as a standalone tyre maintenance crew with sufficient knowledge and experienced in tyre management.

## 4. DISCUSSION OF FINDINGS

Heavy mining equipment tyres are designed and engineered to handle the load and operating environment in which they work. They need to handle the weight, speed and surface conditions and at the same time remain durable.

Therefore, before looking at the factors that could have caused the numerous premature tyre failures at ABC Mine, it is important to understand the tyre construction and selection criteria. Figure 20 shows a section of construction for a heavy equipment tyre.

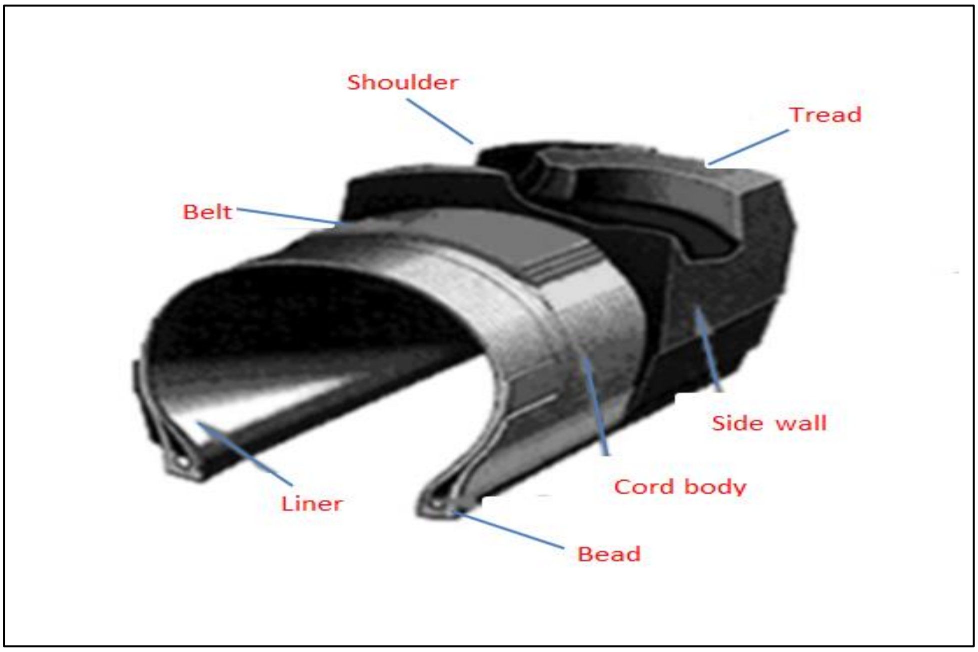


**Figure 20: Tyre Construction**

*Tread*

The tread is the outermost covering of the tyre, and is that part which comes into contact with the road surface. It is, therefore, designed to protect the body of the tyre from cuts and wear. Depending on the intended use of the tyre, the rubber compound applied to the tread will be changed to customize cut tread pattern.

*Sidewall*

The side walls are composed of flexible, crack resistant rubber, and protect the carcass from damage. For jobs where chuck holes, large rocks, etc. are a problem, tyres with high cut resistant sidewalls are used. The sidewalls are designed to cushion the body plies from shock and cutting, while being able to flex and bend without cracking. The sidewall must also be able to withstand the ravages of the weather without deterioration.

*Bead*

The beads fix the tyre to the rim to support the load.

*Liner*

In tubeless tyres, this is composed of two or more layers of rubber, designed to retain air or liquid under pressure. The inner walls of tubeless tyres are lined. The liner is made of an air-impermeable rubber compound and is comparable to tubes used in tube type tyres.

*Belts*

In radial tyres stabilizer bias ply belts under the base rubber give added protection to the radial plies underneath and determine the shape of the footprint.

*Cord Body*

The compressed air in a tyre supports the load placed on the tyre. The cord body, also known as the carcass forms a semi-rigid frame for the compressed air, but it is flexible enough to absorb some shocks and jolts. The carcass of the bias tyre consists of a number of rubber-coated layers of fabric called piles. As such the carcass determines the strength of the tyre and the ability to flex.

*Shoulder*

The shoulder is the point where the tread meets the sidewall.

*Choosing a Correct Tyre*

Off-road tyres for Heavy Equipment come in different brands or types. The type of tyre required for a specific task depends on the kind of equipment to be fitted on, and the application. The tyres are rated as E, L, or G. E is for Earth-mover equipment such as Scrapers, Articulated Dump or Rigid Dump Trucks. L is for Loaders and Dozers and G is used for Graders. Loader tyres or L tyres will generally have more sidewall protection due to the typical terrain they operate from, whereas a transport tyre on an earthmover will not have the same level of sidewall protection, but can handle the stresses of carrying loads at higher speeds.

The tread pattern is equally a significant aspect to consider when selecting a tyre. The biggest factor when determining the tread type to use is the job-site or the typical terrain the equipment operate in. For common Loader applications an L2 or L3 is recommended. An L2 tyre gives maximum traction and cleaning ability in sand and soft conditions. An L3 tyre is used in general loading applications that require more resistance to scrapes and impacts, for example in rocky lots. For instance, an L3 tyre has more durable rubber than an L2 tyre. L5 construction tyres are the toughest. They offer deep tread and longer tread life, and extreme durable, chip resistance rubber for quarries. The added protection however, does come at higher price because there is typically a lot more material used in an L5 tyre than an L4 or L3 tyre.

Heat and speed are two other specifics that have to be considered in selecting a tyre for a mining Dump Truck. Truck tyres experience different modes of heat-related fatigue failure in operation due to inherent material defects that grow into visible cracks under service loads, speed on the other hand, raises internal temperature of the tyre. As such, it is important to consider both speed and ambient temperature when selecting a tyre. To achieve this, site TKPH must be calculated and compared with the tyre TKPH. A tyre is suitable for the site conditions if it meets the condition:

i. $Tyre\ TKPH \geq Real\ Site\ TKPH$

The variable TKPH is used to evaluate a tyre's capacity to carry a load at a given speed without thermal damage to the tyre, with reference to an ambient temperature of $38^{\circ}C$, where K2=1.To get the real site TKPH, two coefficients apply.

i. Cycle length (K1 Coefficient) - For any cycle length exceeding 5Km, the K1 coefficient must apply.

ii. Site ambient temperature (K2 Coefficient) - The Standard ambient temperature is $38^{\circ}C$. For a given speed, a site temperature higher than $38^{\circ}C$ increases the real site TKPH. Conversely, a temperature lower than $38^{\circ}C$ decreases the real site TKPH.

The temperature coefficient is calculated as:

$If\ T_A \leq 38^{\circ}C$

i. $Vm/[Vm - (0.25 \times (T_A - 38))]$

$If\ T_A \geq 38^{\circ}C$

i. $Vm/[Vm - (0.40 \times (T_A - 38))]$

Where:

Vm – Cycle average speed

$T_A$ – Ambient temperature

K – Coefficient

The recommended ambient temperature to use is the 'maximum temperature in the hade' during the hottest period of the year. This data may be obtained from the local meteorological department.

Dump Truck tyre failures are predominantly caused by operating conditions, namely Truck speed, road obstacles, inflation pressure, excessive Truck weights, substandard haul road designs, ozone concentration, and inherent tyre design and manufacturing flaws. High speed operating sites (e.g., hard rock mines) often experience belt separation in tyres during cornering maneuvers of the ultra-size Trucks. Uneven load transfer to tyres on poorly designed super elevation in curved sections of haul roads may result in overloading and subsequent reduction in tyre performance. Although it is the inflation pressure that carries the load, Truck tyres are often overloaded beyond their pressure capacities, leading to tread and ply separation and sidewall cracking. On the other hand, adjusting inflation pressure to compensate for excessive loads may result in rapid tread wear, loss of strength in reinforcements, and impact breaks and cuts (Tyre maintenance manual, 2013).

Further, Willet (1974) provided mathematical relationships describing the energy loss per cycle per unit volume under three loading states: constant strain amplitude [Equation (i)], constant stress amplitude [Equation (ii)], and constant strain and stress amplitude [Equation (iii)]. He noted that in practice, a loaded tyre may be subjected to all three conditions:

i. $W = \pi \varepsilon_o^2 E''$

ii $W = \pi \sigma_o^2 \, E'' / (E^*)^2$

iii $W = \pi \varepsilon_o \cdot \sigma_o \tan \delta$

A combination of these loads results into temperature generation in a rolling tyre, hence precaution has to be taken to ensure heat generated in a tyre does not cause damage. This brings about the concept of TKPH into effect.

***Failure Analysis***

As earlier indicated, the mine recorded the tyre failure modes, but did not go into detail to investigate the root cause of the premature tyre failure.

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*Sidewall Failure*

Sidewall damage was found to be one of the leading causes of tyre failures at the mine. The mine attributed this kind of failure to operators driving too close to berms and high bank faces. These raised surfaces usually contain rocks and other hazards that may slash the tyre sidewalls. Other causes of sidewall damage identified though of low impact include:

i. Running in Ruts – though running a tyre on a rutted road damages the sidewall and puts great stress on the carcass when entering and leaving the rut, there were no deep ruts along the way to cause sidewall cuts. Once in the rut, a tire will wear unevenly due to surface variations.

ii. Under-inflation – only three tyres were detected to be underinflated and these were immediately corrected. Tyres that are underinflated experience significant sidewall deflection, especially when the Truck is travelling under load. The result is higher tread wear, stress in tread and plies, weakened bonding and increased heat build-up. All of these create shortened tyre life. The vital benefits of appropriate inflation comprise providing the tyre with maximum ground contact area, optimal sidewall flexibility and reduced temperature levels.

iii. Under-inflation – two tyres were found to be underinflated and after inspection, it was established that both tyres were leaking from the O ring. Tyres that are underinflated experience substantial sidewall deflection, especially when the Truck is moving under load. The result is higher tread wear, stress in tread and plies, weakened bonding and increased heat build-up. The key benefits of proper inflation include providing the tyre with optimum ground contact area, maximum sidewall flexibility and reduced heat levels.

iv. Excessive Speed – From the VIMS downloads, four vehicles were noticed to have been over-speeding on separate instances, the route from which these vehicles were operating from were fairly smooth with no spills. This condition could not cause serious damage the Truck tyres. Sections of haul road that have a washboard profile can give the Truck's operator a roller-coaster ride, especially if he or she is running over them at high speed. These conditions are also very hard on the sidewalls of the Truck's tyres. Too much bouncing may even cause tyres to momentarily leave the road surface, further amplifying sidewall flexing. Damage from excessive flexing is not immediately noticeable, but is cumulative and can be hard to spot in its early stages. Excessive speed in corners also has a similar effect. It puts too much stress on the tyre sidewalls.

v. Spilled Material on Haul Road – The roads were fairly clean of spilled materials, though minor spills were noted in isolated areas. These could however, cause penetration into the tyre bead, but not severely.

vi. Bumper Blocks – At two points, bumper blocks were found with tyre-marks implying some vehicles were running over the edges of bumper blocks, however, the marks were not significant. The edges of a concrete bumper blocks at the dumping area can be a severe tyre hazard.

vii. Windrows – Some tyre marks were seen on the windrow near the loading area. Windrows created by normal grader road maintenance can cause sidewall flexing when haul Trucks pass over them. Sometimes, straddling a windrow is unavoidable. It is therefore, important to avoid windrows and if one was to cross it, it must be crossed from a section free of large boarders of rock.

viii. Dry Steering – this was observed from the deep tyre marks at the parking area, however, it was difficult to determine how often this practice was applied as the twelve operators interviewed denied conducting such practices. However, the digging from the parking area implied dry steering occurred. Dry steering refers to the practice of turning the Truck front wheels while it is stationary. This action causes excessive force on the sidewalls of the tyres.

*Bead Failure*

Some tyres checked on site had some scratches on the bead, mostly sustained during assembling, however, this kind of failure was not significant. When the bead fails, the tyre quickly deflate, explode or the tread may separate. Since the bead is kept in place by air pressure, any defect during manufacturing or mounting can result into a tyre failure. Low tyre pressure can also cause the bead to fail, if the pressure is not sufficient to hold the bead in place, the bead will come out of place and the whole tyre may separate from the wheel. However, most writers have attributed bead failure to poor design, manufacturing or during assembling or demounting. This kind of failure was experienced on eleven tyres and the mine

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attributed this to Trucks running over spilled rocks along the way. Though the assumption may be correct, the road ways did not contain rocks that could warranty belt separation.

A belt separation in a tyre results from an area of no adhesion between two adjacent tyre components. These components are designed so that they completely adhere to each other. Separations often result when pressurized air within the inner liner of the tyre is allowed to pass through the liner and enter into the structure of the tyre, this is known as the intercarcass pressurization. Once inflation pressurized air enters the structure of a tyre, the air can drift along and through the body cords and belt cords of the tyre. Intercarcass pressurization is quite a dangerous condition because it can cause tyre separations and blowouts. Once the air is allowed to pass through the liner and into the structure of the tyre, the pressurized air can mechanically force components apart. These components of the tyre are not intended or designed to be subjected to highly pressurized air. As pressurized air migrates through the inner liner of the tire, the air can slowly move through and around the tyre. This allows separations to occur in almost any location throughout the tyre, or in multiple locations. Multiple separations can also grow large enough so that they connect with other separations, increasing the size of the overall area of separation.

*Belt Failure*

Belt separation was identified in five tyres which were not recorded by the Planning office. The comment from the mine was however that, belt separation was as a result of the operators negotiating deep bends at high speed. Though, the theory stands true, the life of the failed tyres was too short (773, 1005, 896, 620 and 1120 hours). The number of hours each tyre had done were written on the tyre sidewall. It was however, difficult to validate these numbers as no one claimed responsibility to have written them.

*Shoulder Failure*

Though from the Maine maintenance records, no tyre was recorded to have had shoulder failure, 78 tyres displayed serious shoulder damage. From visual inspection, the shoulder failure was not as a result of running over sharp bodies such as rocks or from scuffing, but could have been due to rubber deterioration as no physical impressions were seen from the tyre surface. This condition is likely to have been created as a result of the wrong TKPH of the tyre.

*Zipper Failure*

Two tyres failed due to suspected Zipper failure though the mine only registered it as blow-out and no investigation was conducted to determine the cause of failure. Both tyres failed from the sidewall and upon inspection, the tyres did not have any visible impressions from the outer side, indicating the tyres did not suffer any external impact or damage. When the records were checked, both tyres were inflated to correct pressure and operated from the same route where all other Trucks operated. The other point noted was that, both tyres failed while loading, however, the VIMS downloads did not show any sign of overloading. Zipper failure is a kind of failure where there is almost no way of determining whether a tyre is subject to failure, usually, the sidewall of the tyre fails catastrophically. This may occur from operating a tyre well outside its design load, speed or inflation pressure limits, leading to a weakening in the steel cords of the tyre's plies. Secondly, this failure mode may occur through any accidental sidewall damage which may have weakened the steel cords of the tyre. This failure type may be termed as a 'subset failure' as it results from various causes. Therefore, determining of TKPH before using a tyre becomes critical as one of the many ways to prevent this kind of failure which may cause serious injury to personnel. Though certain methods such as finite element methodology and the virtual crack closure technique may be employed in order to find out physical quantities which control fatigue life of a structure in order to predict fatigue life of a tyre, predicting zipper failure could be challenging. The most important thing to do is to take all safety precautions when handling tyres, their stored energy and mass can cause serious damage to both personnel and equipment.

*Tread Failure*

The mine attributed the rapid tread wear of tyres to rough roads and sharp bends along the haulage. Further, it was also concluded that operators' competence contributed to this kid of failure due to skidding during take-off. However, looking at the condition of the roads, the roughness was moderate and could not cause massive damage to tyres. Additionally, the route had only two sharp bends close to dumping point. Moore (1980) presented a unified approach to the study of friction and wear in rubbers and tyres. He outlined two contributions to the coefficient of rubber friction: adhesion and hysteresis. The study showed that the adhesion component of friction leads to abrasive or cutting wear on extremely harsh surfaces. They also suggested that the hysteresis mechanism of friction results in fatigue wear on surfaces with smooth and rounded asperities. All the conditions highlighted by the mine as being the major cause of the numerous tyre tread failure did not warranty massive damage to the tyres. This was also confirmed through a comparative analysis which showed that tyres of a different model used on the CAT775 Dump Trucks and operating from the same area did not fail prematurely.

From the records viewed and physical inspection of the disposed tyres, 64% of the failed tyres presented worn-out treads, however, though the failure was recorded as mere 'tread failure', the number of hours in service were below target, implying other factors contributed to the rapid wear. There was also a lot of tyre rubber pills along the way falling off moving Truck tyres. Tyre fatigue life is known to be influenced by a class of factors: thermomechanical loading history, irregularities in rubber formulations, environmental factors, and effects due to the dissipative nature of the rubber materials. Through observation, the first factor suspected to have been causing such kind of failure was heat. From the study conducted by Lindeque (2016), it was noted that the most common reason for scrapping 59% of the tyres at the mine he investigated was due to what was termed as wear (failure classified by the mine), however, he said, any tyre that is classified as worn-out should have reached its maximum life achievable due to a specific wear rate. It was also noted that, the achievable tyre life for each Truck was significantly higher than the recorded tyre life and this was due to abnormal wear of tyres that failed. However, the cause of failure was not adequately examined by the mine management.

Kainradl and Kaufmann (1972) studied the effect of numerous viscoelastic properties of tyre compounds on heat buildup. The study varied rubber compounds used in the tread-cap, tread-base, and rubber matrix of the rayon cord for 12.00-20 tires to reflect alterations in their viscoelastic properties. Needle thermocouples were used to measure the operating temperatures of the tyre shoulder region while the tyres were on the test wheel. The authors used multiple regression analysis to investigate which combinations of viscoelastic properties of the rubber compounds would give a linear, significant correlation to the heat buildup in the tire. They found out that, the greater contribution (25–30%) to the heat buildup came from the tread-base due to its loss factor, followed by the carcass (20%) also by its loss factor, and the least contribution (10%) from the tread-cap due to its loss compliance. The contributions of the tyre cord to the heat buildup, however, remained undetermined in this work. This aspect led to an investigation of the tyre suitability for the site. To determine whether temperature contributed to tyre failure, TKPH for the site was calculated and compared with the tyre TKPH.

*Tonne Kilometer Per Hour (TKPH)*

The data for calculating TKPH was collected:

i. Machine type – CAT789B Dump Truck

ii. Number of tyres – 6

iii. Tyre size – 40.00R57

iv. Unloaded vehicle weight – Front 54.147Tonnes. Rear 86.705 Tonnes

v. Pay load – 180 Tonnes

vi. Gross weight – 320.852 Tonnes

vii. Load per tyre (unloaded) – Front 27.074 Tonnes. Rear 21.676 Tonnes

viii. GVW Distribution – Front 33%. Rear 67%.

ix. Loaded axle load – Front 105.881 Tonnes. Rear 214.971 Tonnes

x. Load/tyre loaded – Front 52.941 Tonnes. Rear 53.743 Tonnes

xi. Mean load/tyre – Front 40.007 Tonnes. Rear 37.709

xii. Cycle length – 7.2 Kilometers

xiii. Cycle time – 0.52 hours

xiv. Average speed – 33Km/h

xv. Site temperature – 42˚C

TKPH = Qm x Vm x K1 x K2

Where:

Qm – load per tyre, loaded

Vm – Average speed

K1 – Cycle length coefficient

K2 – Ambient temperature coefficient

It should be noted that, K1 applies only to cycle distance exceeding 5km. Since the ambient temperature for the site exceeds 38˚C, the formula (i) shall be uses:

i. $Vm/[Vm - (0.40 \times (T_A - 38))]$

ii. $34/[34 - (0.40 \times (42 - 38))]$

iii. 34 – 1.6 = 32.4

iv. 34/32.4 = 1.049

∴ K2 = 1.049

At 42˚C, the K1 coefficient is 1.06

TKPH (Front) = 40.007 x 34 x 1.049 x 1.060 = 1512.503

TKPH (Rear) = 37.709 x 34 x 1.049 x 1.060 = 1425.624

The TKPH for the front tyre is 1512.50 and the rear 1425.62. The tyre TKPH is given in given Table 2 provided by the tyre manufacturer.

**Table 2: Radial OTR Tyre Selection Chat (Tyre Supplier)**

| Tire Size | Compound/ Construction | Catalog Number | Sipes/ No Sipes | Industry Code | Load/ Speed Index | Load Rating | Rim Width Code | Flange Height Code | Outside Diameter in (mm) | Section Width in (mm) | Tread Depth in (mm) | Load @ Inflation lbs @ PSI (kg @ bar) | TMPH (TKPH) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 40.00R57 | HV | MHV240 | Sipes | E-4 | 250 B | 2 * | 29.00, 32.00 | 6.0 | 142.1 (3609) | 43.2 (1097) | 105/32 (83) | 132,500 @ 105 (60,000 @ 7.3) | 813 (1186) |
| 40.00R57 | WV | MWV240 | Sipes | E-4 | 250 B | 2 * | 29.00, 32.00 | 6.0 | 142.1 (3609) | 43.2 (1097) | 105/32 (83) | 132,500 @ 105 (60,000 @ 7.3) | 650 (949) |
| 40.00R57 | CV | MFV240 | Sipes | E-4 | 250 B | 2 * | 29.00, 32.00 | 6.0 | 142.1 (3609) | 43.2 (1097) | 105/32 (83) | 132,500 @ 105 (60,000 @ 7.3) | 488 (712) |
| 40.00R57 | H2 | MH2240 | No Sipes | E-4 | 250 B | 2 * | 29.00, 32.00 | 6.0 | 142.1 (3609) | 43.2 (1097) | 105/32 (83) | 132,500 @ 105 (60,000 @ 7.3) | 772 (1127) |
| 40.00R57 | W2 | MW2240 | No Sipes | E-4 | 250 B | 2 * | 29.00, 32.00 | 6.0 | 142.1 (3609) | 43.2 (1097) | 105/32 (83) | 132,500 @ 105 (60,000 @ 7.3) | 618 (902) |
| 40.00R57 | C2 | MF2240 | No Sipes | E-4 | 250 B | 2 * | 29.00, 32.00 | 6.0 | 142.1 (3609) | 43.2 (1097) | 105/32 (83) | 132,500 @ 105 (60,000 @ 7.3) | 463 (676) |

The results of the real site TKPH calculated and the tyre TKPH of the tyre provided by the tyre manufacturer were compared as shown in Table 3.

**Table 3: TKPH Comparison**

| Site TKPH | | Tyre TKPH |
|---|---|---|
| Front | Rear | Manufacturer's |
| 1512.50 | 1425 | 1127 |

The manufacturer's TKPH for the tyre used at ABC Mine was 1127, whereas the real site TKPH indicated 1512.50 for the front and 1425 for the rear tyres. The tyre TKPH was less than the real site TKPH, as such, failing the condition; Tyre TKPH ≥ Real Site TKPH.

## 5. CONCLUSION

Mine ABC faced a low tyre life condition from the purchased lot of the CAT 789 Dump Truck tyres during the period January 2019 to April 2020, the time of the study. The average tyre life experienced was 1100 from the expected tyre life of 5000 hours. The mine management however, attributed the numerous premature tyre failures to poor operator practices and the harsh environmental conditions.

The results of the study, however, showed that, the mine did not have a comprehensive tyre management program; tyre failures were recorded and the data filed from the maintenance planning office for easy access, nevertheless, no further detailed analysis was conducted to determine the actual cause of failure. Additionally, the haul roads and the loading areas were not maintained to standard, the maintenance side of the tyre management system was found to be ineffective; the tyre maintenance practice, storage, and monitoring were not adequately managed. On the other hand, the load and haul side of the tyre management system was equally weak; there were no proper road maintenance audit records available to show the condition of roads from which informed decisions could be made.

Though all these factors contributed to the low service hours of tyres at ABC Mine, the main contributing factor as indicated from the study findings, is the wrong selection of the tyre where the tyre TKPH was lower than the real site TKPH.

## 6. RECOMMENDATIONS

To avoid a similar occurrence, the study recommends that ABC Mine should at all times compare the tyre TKPH with the real site TKPH before purchasing tyres for any application. Further, the mine should establish a road maintenance crew independent of the mining section to avoid conflict of interests. The tyre maintenance crew must be firmed up by engaging a tyre expert to lead the already existing crew and it is also important for the mine to enhance the level of tyre awareness amongst employees through Toolbox meetings. Visual display of things that affect tyre life should be given to operators, who have the largest impact on tyre life and from the study conducted, they showed the lowest level of tyre awareness.

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