Maintenance strategy optimisation for load haul dumpers used in the South African underground hard rock mine

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Abstract

The purpose of this paper is to outline areas of improvement to optimize maintenance strategy of Load Haul Dumpers (LHD) fleet by determining factors influencing reliability and maintenance cost of LHD fleet used at the underground hard rock mine in South Africa. The stage of product lifetime distribution in which LHD fleet fall under is being analyzed. The study collects operational data comprising of maintenance and financial values. Pareto analysis is performed in order to determine the top twenty subsystems contributing eighty percent of factors affecting LHD fleet reliability. Weibull analysis is also performed to determine the stage of product lifetime distribution in which LHD fleet fall under. The results from the Pareto analysis indicates that fittings and hoses, electrical systems, air conditioning system, engine, brakes and transmission formed part of the top twenty percent which accounted for eighty percent of LHD fleet failures. Pareto analysis also outlined the top twenty percent of subsystems which accounted for eighty percent of total maintenance spend. Tyres also forms part of the top twenty percent which accounted for eighty percent of both total maintenance spend and LHD fleet failures. The LHD fleet is in the middle of the wear-out stage as determined using the Weibull distribution. The method of Pareto chart for determining subsystems which accounted for eighty percent LHD fleet failures and maintenance spend uses real case study data. The Weibull distribution also used real case data. The research study used a twelve month period for both maintenance and cost data.

Keywords
Reliability, Weibull analysis, Pareto analysis, failure distribution, subsystems.

1. Introduction

The underground hard rock mine is in the process of expanding its underground operation with the intension of increasing the life of Mine (LOM) with other 10 years of operation, thus creating jobs and sustainable income for its current employees and shareholders. A fully mechanized Mine aims to achieve this expansion with aid of developing a block cave underground section, this requires the utilization of Drill Rigs, Load Haul Dumpers (LHD), Articulated Dump Trucks (ADT) and Utility Vehicles (UV) for drilling, loading, hauling and material transportation respectively. After the development of a block cave underground mining section, drill rigs will not be employed or utilized as the block of ore caves due to gravitational force rather than by means of drill and blast techniques. The fleet of LHD remains the main fleet type which would be required for production purposes, hence the focus of this research study is on optimizing maintenance strategy for LHD which are currently in use at the said mine. LHD are utilized for loading of ore for intermediate mechanization in underground mining (Samanta et al. 2004). LHD are dominant machines in Intermediate technology and plays an important role in overall mine production. It is essential that LHD machines be reliable and maintained effectively (Samanta et al. 2004) and (Dindarloo, 2016). The Mine witnessed low LHD fleet availability in 2016, 2017 and the first two months of 2018. The trend of low machine availability resulted in loss of production time in the development phase. Maintenance cost for seven LHD fleet size is consistently high for the same period, particularly in 2017 and 2018. According to (Hussan et al. 2014) and (Vayenas and Peng, 2014), maintenance cost for underground mobile machines accounts for 30 to 65 percent of the Mine's total operation costs.

The Mine's expansion project team is equipped with a fleet of seven LHD comprising of four Sandvik-LH 514, one Sandvik-LH 621 and two Caterpillar-1700. All LHD are of similar construction comprising of the power train (Engine, Torque Converter, Transmission, Axles and tires), Frame (Front, Rear and Central hinge), Hydraulics System for Steering and bucket operation (Boom system, Lift cylinders, dump cylinders, servo control valve, main valve, pump, fittings and hoses) and brakes (pressure accumulators, brake pedal valve, charging valve), a graphical representation of LHD is shown in Figure 1 (Sandvik LH514 Technical Specification, 2013). The subsystems discussed above plays an important role in understanding the product life cycle of LHD, the estimation of spare parts and the estimation of maintenance budgets (Ghodrati and Kumar, 2005). The above-mentioned remains a challenge for development team employed for the expansion project.

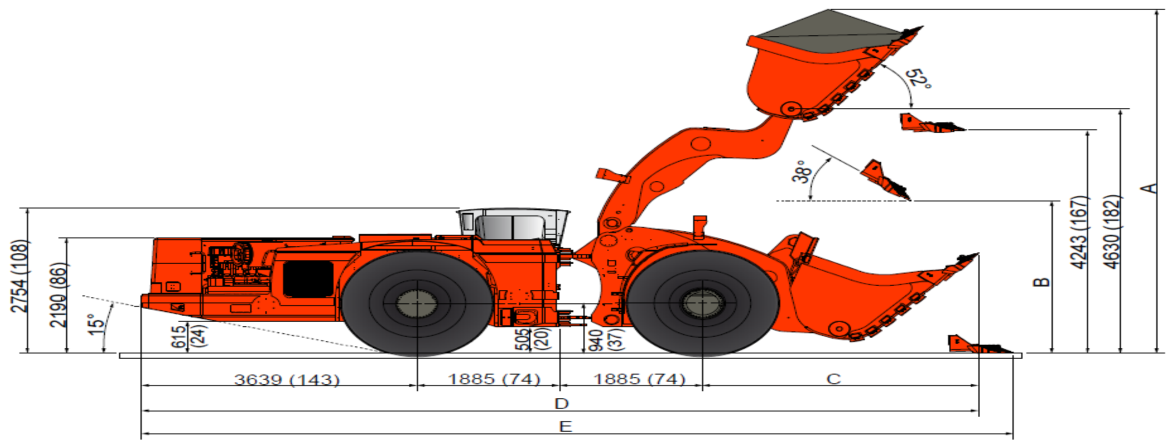

Figure 1. Technical Schematic - Sandvik LH 514**.**

2. Literature Review

Industry at large is focusing on getting the best out of asset used to achieve production, this have been a focus point and resulted in asset managers to investigate best maintenance strategies at low cost in order for companies to realize profits. Optimization of maintenance strategy can be realized should the correct maintenance philosophy be implemented and executed at low cost without compromising system's quality. According to (Fazlollahtabar and Niaki, 2018) and (Christian and Madu, 2005), most of failures are due to external factors, however, understanding the manner in which the system functions is critical in optimizing maintenance strategy of that system. According to the study done by (Fazlollahtabar and Niaki, 2017), Reliability Block Diagram (RBD) assist in understanding subsystems or components which form an integral part of the system. The study further suggests that RBD makes fault finding simpler to improve equipment's availability (Fazlollahtabar and Niaki, 2017).
According to (Velasquez and Lara, 2018), reliability life cycle of a system may be outlined by making use of Weibull distribution to determine that system's stage in the bathtub curve. The study further suggests that the product life span, the cost of maintenance and the number of breakdowns and associated cost can be used to determine the maintenance budget of that product (Velasquez and Lara, 2018). The content reviewed in the literature addresses the challenges faced in field of maintenance of the mining equipment, however, there is a lack of maintenance strategy optimization for mining equipment, particularly t in the South African mechanized underground Mines. This study attempts to recommend areas of improvement in order to optimize the maintenance strategy of LHD fleet used in the South African underground hard rock Mine.

This research study consist of three objectives:

a) Analyze the LHD fleet data relative to best practice to determine categorization; and
b) Data centric determination of factors influencing LHD fleet reliability and the cost of maintenance; and
Data centric identification of improvement to optimize maintenance strategy of LHD fleet utilized at the expansion project of the hard rock underground mine.

3. Methodology

The study attempts to use triangulation data approach, with LHD fleet failures data, financial data and proven theories from literature relating to maintenance strategy optimization forming part of triangulation approach. The research study adopts reliability block diagram to analyze subsystem failures a population of seven LHD fleet, Figure 2 is a series network of LHD subsystems. According to (Zulkafli and Dan, 2016), Weibull distribution is used to determine maintenance performance indicator relating to system failures and reliability. A shape factor β (condition of the system) and system characteristic life η are determined. This study further attempts to use Weibull distribution to determine the lifetime stage of the LHD fleet. According to (Velasquez and Lara, 2018), the bathtub curve shown in Figure 3 below is a hypothetical failure rate versus time. Three stages of a system comprise of infant mortality stage, failures occur in the early phase ($\beta < 1$), normal life, system is reliable as less wear-out failure occurs ($\beta = 1$) and end of life wear-out, the system's wear-out failure increases with time ($\beta > 1$) (Razali et al. 2009).

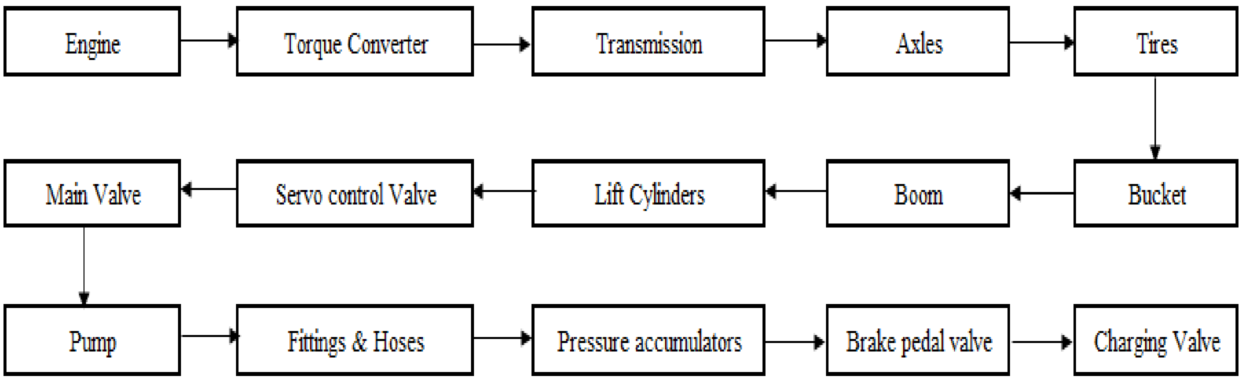

Figure 2. LHD subsystems – Series network configuration.

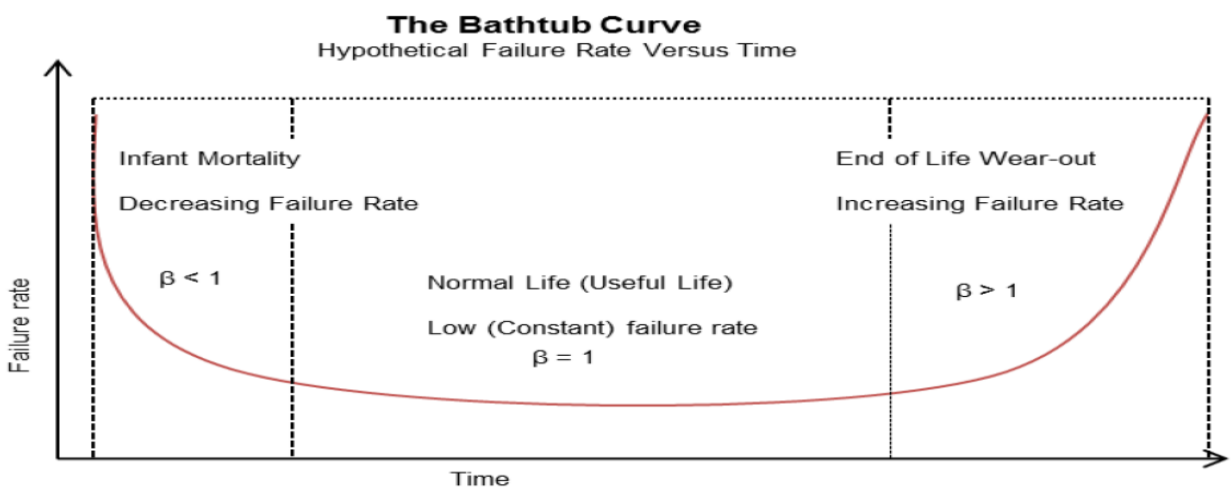

Figure 3. Bathtub Curve based on time-dependent failure rate.

According to (http://www.au.af.mil/au), Pareto charts are used to determine areas or factors (usually top twenty percent) which accounts for eighty percent of total unwanted events, Pareto chart assist the user to determine factors which requires interventions. This research study adopts the Pareto chart capability to rank subsystems from highest cost to lowest cost and subsystems failures from lowest to highest, the objective is to illustrate trends to outline twenty percent groups which may have an impact for eighty percent of the total maintenance cost and LHD fleet failures respectively.

4. Results and Discussion

This section addresses archival data gathered from the hard rock underground mine maintenance management system. The operational data analysis consist of number of sub-system failures as shown in Figure 3. Total failure distribution per LHD and the top twenty LHD with highest number of failures is also outlined in Figure 2. The study highlights Pareto analysis of subsystem failures is also performed. The final part of this section of the study discusses archival data acquired from the hard rock underground mine finance system. The report shows the cost distribution per LHD, the top twenty LHD which accounted for eighty percent of the total maintenance spend were determined. The cost distribution per subsystem and the top twenty subsystem consuming eighty percent of the total maintenance spend is also discussed.

LHD subsystems failures

A list of subsystems and number of failures per subsystems, relative percentage and cumulative percentage for a population of seven LHD fleet is outlined in Table 1 below.

Table 1. LHD subsystems failures

Subsystems	No. of failure per subsystem	Relative Percentage	Cumulative Percentage
Fittings and Hoses	199	21%	21%
Electrical	155	17%	38%
Air Con	96	10%	48%
Tyres	84	9%	57%
Engine	65	7%	64%
Brakes	64	7%	71%
Transmission	62	7%	78%
Boom	34	4%	82%
Bucket	30	3%	85%
Pump	16	2%	87%
Servo Control Valve	9	1%	88%
Axles	5	1%	88%
Torque Converter	4	0%	88%
Main Valve	4	0%	89%
Charging Valve	3	0%	89%
Other	100	11%	100%
TOTAL	930	100%	

Table 1 above presents a quantitative explanation of the LHD sub-systems failures over the time frame of the study (February 2017 to January 2018). A total of 930 failures are observed on 7 LHD (total population). The patterns of sub-systems is different from one sub-system to the other. Fittings and hoses registered the highest (21%) fleet breakdowns. Most of fleet breakdowns (78%) are due to fittings and hoses failures, electrical components failures, cabin air conditioner failures, tires failure, engine failures, brakes failures and transmission failures.

Pareto analysis for sub-system failures

Pareto Chart is used to show subsystems failure distribution as represented by the blue bars (Y-axis) in Figure 4. The principle of Pareto chart shown in Figure 4 is to determine that eighty percent of failures are contributed by twenty percent of subsystems (http://www.au.af.mil/au). The red horizontal line represent the eighty percent mark (X-axis), the gray line represent cumulative percentage of subsystem failures (X-axis). Figure 4 determines that top twenty percent sub-system failures cause eighty percent of the LHD fleet failures. The top twenty percent comprise of fittings and hoses, Electrical components, driver's cabin air conditioner, tyres (non-maintenance related subsystem), engine, braking system and transmission. According to (Velasquez and Lara, 2018), there is required efforts from the maintenance department to address the subsystem forming part of top twenty percent. The bottom eighty percent sub-system failures comprise of boom, bucket, pump, servo control valve, axles, torque converter, main valve, charging valve and other failures. Twenty percent of the LHD fleet failures were caused by the bottom eighty percent sub-system failures. Although tyres are managed by the maintenance department, tyre failures do not necessarily determine the quality of maintenance done by the maintenance personnel. As a result of this, the maintenance team must give priority to fittings and hoses, electrical, air conditioning, engine, transmission, boom and brakes over tyres.

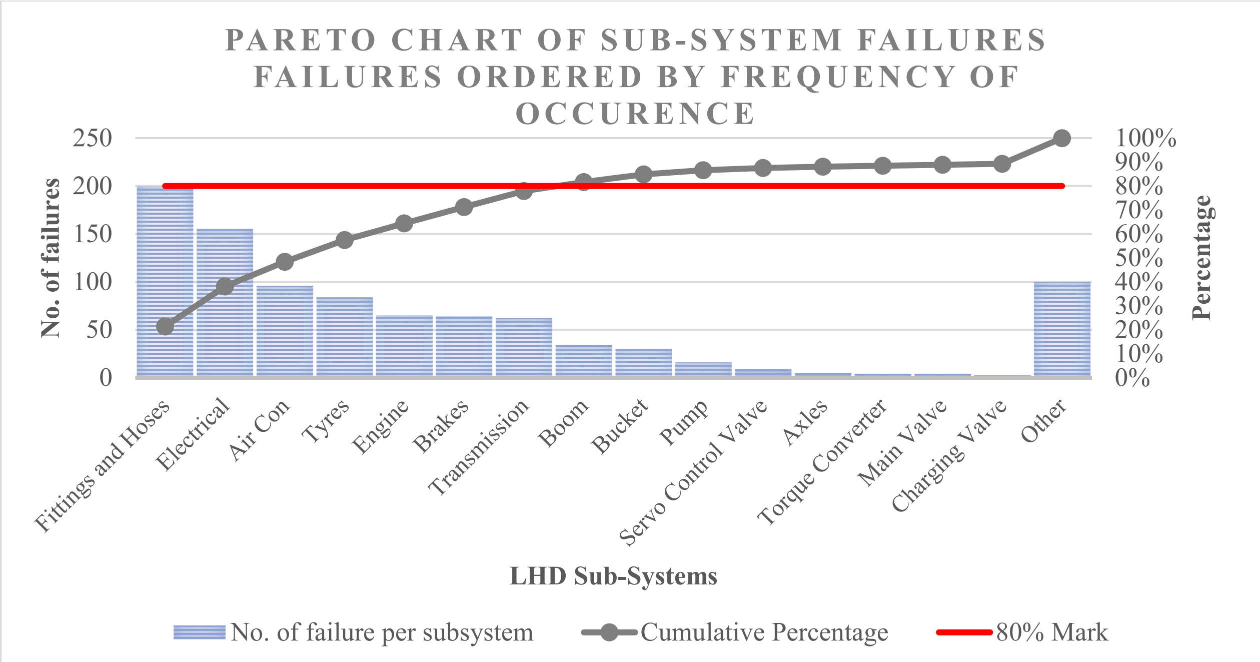

Figure 4. Pareto analysis of subsystems failures

Cost distribution analysis per Sub-System

This section presents a list of subsystems of seven LHD fleet and associated cost, relative percentage and cumulative relative percentage of maintenance cost is also outlined in Table 2 below.

Table 2 Cost distribution analysis per subsystem.

Subsystems	Cost	Relative Percentage	Cumulative Percentage
Tyres	R5 730 027,15	27%	27%
Fittings and Hoses	R3 005 014,97	14%	41%
Engine	R2 553 449,25	12%	53%
Maintenance	R2 211 886,40	10%	63%
Boom	R1 604 364,54	8%	71%
Electrical	R1 363 276,72	6%	77%
Transmission	R1 118 688,06	5%	83%
Bucket	R884 013,39	4%	87%
Air Con	R500 678,53	2%	89%
Servo Control Valve	R434 032,95	2%	91%
Pump	R415 218,75	2%	93%
Brakes	R322 867,91	2%	95%
Axles	R230 928,44	1%	96%
Main Valve	R80 733,18	0%	96%
Charging Valve	R6 011,66	0%	96%
Torque Converter	R0,00	0%	96%
Other	R890 829,79	4%	100%
TOTAL	R21 352 021,69	100%	

Table 2 shows that fittings and hoses accounted for 14% (R3 Million) of the total maintenance cost. The majority of the maintenance cost (83%) is accounted by tyres, fittings and hoses, engine sub-system, special maintenance done by Original Equipment Manufacturer for either LHD or fire suppression system, electrical system, boom, and transmission sub-system.

Pareto analysis for sub-systems maintenance cost

Pareto Chart is also used in this section to show subsystems maintenance spend as represented by the blue bars (Y-axis) in Figure 5. The principle of Pareto chart shown in Figure 5 is to determine that eighty percent of the subsystem maintenance spend comes from top twenty percent of the subsystems (http://www.au.af.mil/au). The red horizontal line represent the eighty percent mark (X-axis), the gray line represent cumulative percentage of subsystems from highest to lowest (X-axis).

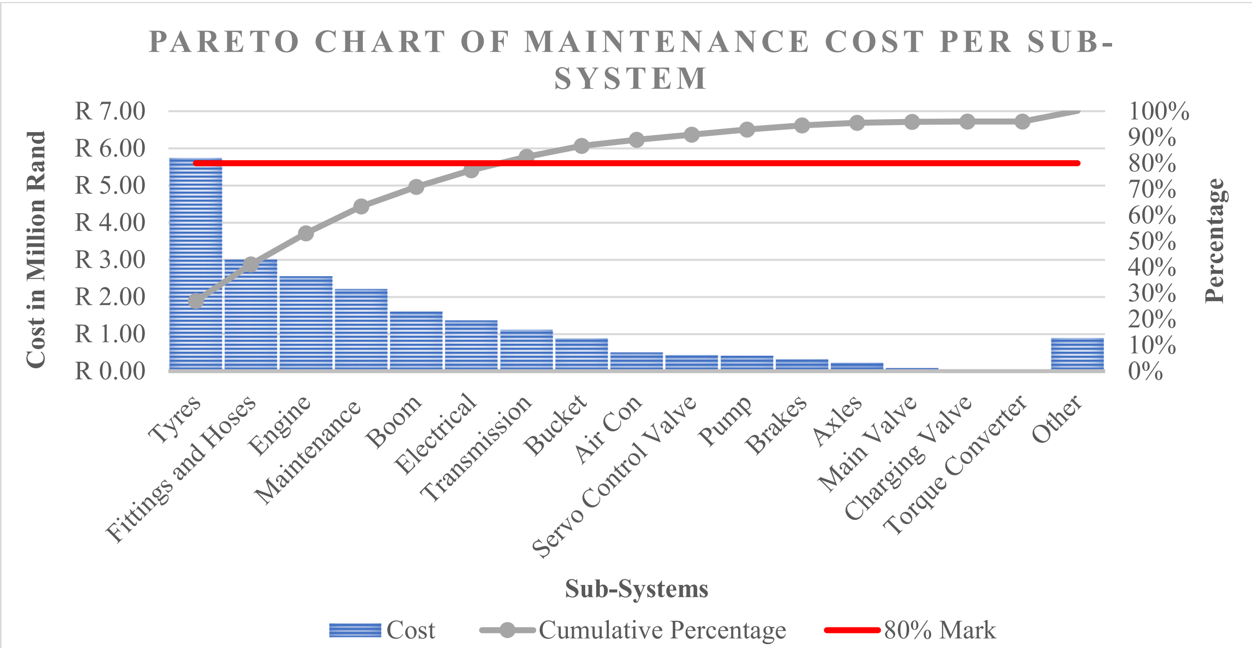

Figure 5. Pareto analysis for system maintenance spend

Figure 5 aim is to determine top twenty percent sub-system maintenance cost which accounted for eighty percent of the total maintenance spend. The top twenty percent includes tyres (mainly due to damages and common wear), fittings and hoses, Engine sub-system, special maintenance performed by the OEM, the boom, transmission and electrical systems. Although tyres budget is accounted for in the LHD fleet total maintenance budget, the maintenance team must give priority to fittings and hoses, engine, special OEM maintenance, boom, electrical subsystem and transmission.

Weibull analysis

The study adopts Minitab 8 software to perform Weibull distribution. Faults data is modelled and the distribution of that data is used to evaluate reliability of the LHD fleet. Early failures occur in the beginning of product life and is presented as such when $0 < \beta < 1$. Constant failure rate is represented when $\beta = 1$, the start of wear-out failure is presented when $\beta = 1.5$, the risk of increased wear-out failure is presented when $\beta = 2$, fast wear-out failures is presented when $3 \leq \beta \leq 4$ and extreme wear-out failures is presented when $\beta > 10$ (https://support.minitab.com). The Figure below presents the stage in the bath tub curve in which the LHD fleet falls under.

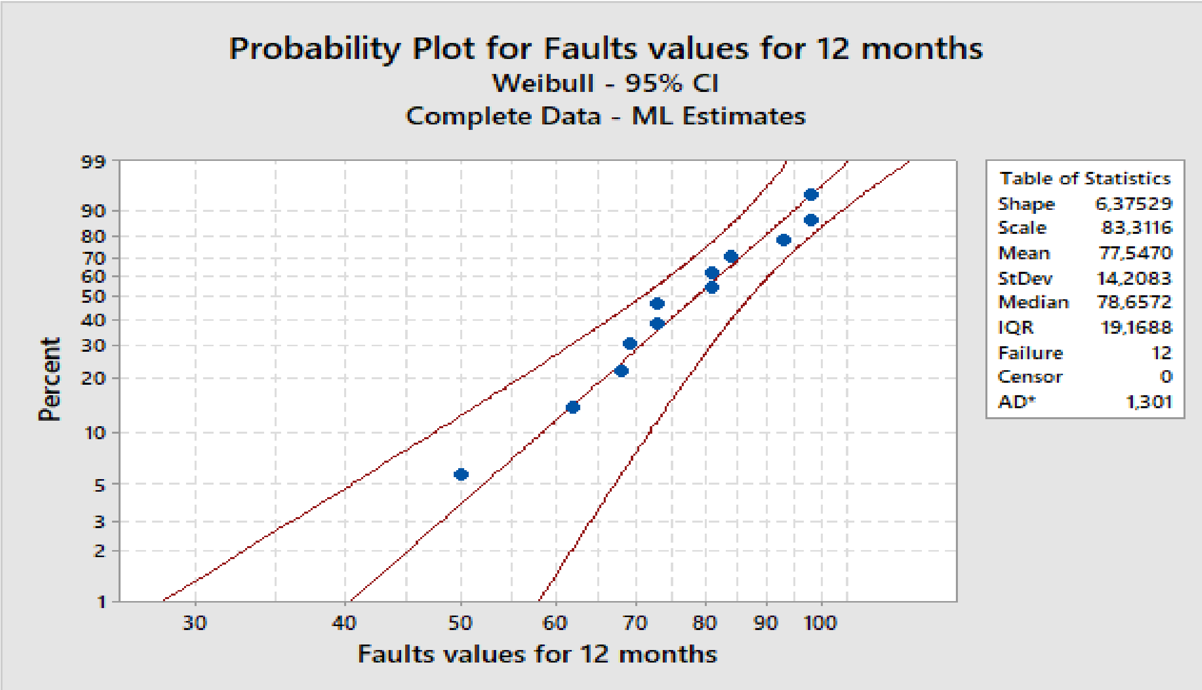

Figure 6. Weibull analysis

The Weibull distribution is commonly used as a lifetime distribution in reliability engineering. Figure 4 shows two parameters (shape and scale). The Weibull distribution represents a decreasing, constant or increasing failure rate (Razali et al. 2009). Figure 6 indicates the shape (β) parameter of 6,37529, the positive correlation of time between failures is confirmed statistically with a P-Value of 0,665 (https://support.minitab.com). According to (Hussan et al. 2014), (Freeman, 1996) and (Zulkafli and Dan, 2016), the LHD fleet concerned is in the middle stage of wear out phase, most failures are due to subsystem reaching predicted life span. The expansion project maintenance team must consider a complete overhaul or refurbishment and replacement of wear out components (top twenty subsystems discussed subsection C and D of this section) as the ideal solution to minimize or prevent further age type of failures (Zulkafli and Dan, 2016), (https://www.automation.com) and (Freeman, 1996).

Conclusion and Recommendations

The research study uses a statistical approach and quantitative method for the collection of data to answer the research questions. Operational data comprised of maintenance and financial values for LHD fleet operating at the underground hard rock mine. The outcome of this study suggests that LHD fleet in question is operating with components or subsystems which are in the middle of the wear out stage in the bathtub curve (research question 1). It is evident that the expansion project maintenance team does not employ condition monitoring techniques to detect possible failures in order to apply preventive maintenance techniques. There is a correlation between four of the top twenty percentile subsystems which accounted for eighty percent of LHD fleet failures and associated cost thereof. The maintenance team must concentrate the effort in attempting to improve reliability and optimization of maintenance strategy as per the following priorities (http://www.au.af.mil/au):

- Priority one – Common top twenty percent subsystems as determined in Figure 4 and 5, such subsystems comprise of fittings and hoses, electrical subsystem, engine and transmission.
- Priority two – the remainder of top twenty percent subsystems presented in Figure 4 (Pareto analysis of subsystems failures), but do not form part of top twenty percent subsystems presented in Figure 5 (Pareto analysis for system maintenance spend), such subsystems comprise of air conditioning and brakes.
- Priority three – the remainder of top twenty percent subsystems presented in Figure 5, but do not form part of top twenty percent subsystems presented in Figure 4, such subsystems comprise of OEM special maintenance cost and the boom.

The underground mine must concentrate on implementing proactive maintenance strategy such as condition based maintenance and enforce a schedule for machine refurbishment.

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Citations:

to this paper should be made as follows: Mpho Manenzhe and Telukdarie, A. (201…) 'Maintenance strategy optimisation for load haul dumpers used in the South African underground hard rock mine, Proceedings of the international conference on Industrial Engineering and Operations Management, Vol. …., No. …., pp ….Toronto, Canada, October 23-25, 2019.

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