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Optimal Maintainability of Hydraulic Excavator Through Fmea/Fmeca

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ABSTRACT: The concept of advanced maintenance management technique in the field of heavy earthmoving mining machinery is recently developed in India, and has taken pace with the demand of the same, rising continuously over the years. This paper indulges into considering of hydraulic excavators, which is a large machinery that is designed for excavation and demolitions purposes. It spreads to various sizes and functions. The development of the mining industry has been escalated largely due to the introduction of different types of excavators. These excavators are used to satisfy various mining, industrial and construction needs. The mining excavators are mainly of two types that are used in modern era namely backhoe and dragline, other being suction excavator, long reach/long arm, crawlers and compact excavators, power shovel etc. The data collected and analysis has been done keeping in mind the vicinity of the coal capital of India, where hydraulic excavator is mainly used. It is so, that the same gets prime focus in the paper. The increased penetration of service of the high yield machines in the above-mentioned sectors have made them really important. Halting or stoppages are seen as the bottlenecks, which disturbs the productivity. Seeing the large benefits, and associated productivity and profit loss, the maintenance engineer felt the need to have advanced maintenance of the same. The paper deals with different faults of the excavator, and based on the data acquired, takes on further steps towards carrying out the FMEA analysis which incorporates into it by estimating Severity, Occurrence and Detection of the considered parts respectively, and then Risk Priority Number (RPN) is calculated, ranging from 1 to 1000. The quantitative approach helps in deciding the various maintenance strategies for the different parts and sub-parts. It is based on the above factors that maintenance plans are initiated, designed and implemented.

I. INTRODUCTION

Open cast mining is the most common method of mine production in the world. In this, the required production is provided by set of various tangible equipment, having variability in types and capacities. Hydraulic excavator is one of them. Being a mega sized equipment; it generally requires a great deal of investment. So, it is necessary to have its partwise maintenance and the its maintenance methodology has to be carefully analysed so that overall maintenance can be carried out to bring to surface the full capacity of the earthmover.

This paper discusses a maintenance strategy and claims to have criticality analysis of components of mine excavators through FMEA/FMECA analysis program. Various functional analysis of the hydraulic excavators and its components has been taken into account so that the maintenance cost be minimized and technical constraints (such as engine, hydraulic and transmission system, break system, electrical and safety system, suspension and track) are efficiently monitored and maintained. These technical constraints depend upon many factors such as
a) Geotechnical parameters,
b) Geological parameters,
c) Mine parameters,
d)Production rate,
e) Equipment specification and
f) Dig ability assessment etc.

Taking into consideration the whole of above factors, maintenance plans are prepared for predicting/accessing equipment’s and their components’ failure. For carrying out the same which is performed continuously at regular interval, we can use data base similar to that monitored by protective devices to detect abnormalities in behaviour, FMEC analysis, FMEA worksheet, Condition based monitoring system. (Kumar Prakash & Srivastava R. K.)

II. LITERATURE REVIEW

Maintenance means the work of keeping equipment or anything in proper condition. It includes activities like service, lubrication, repair and replacement of different parts of the equipment. It is the work done to preserve an asset so that it can perform its function properly. Maintenance keeps the equipment in operable form so that it can be used effectively and efficiently till at least the design life of the equipment. Maintenance activities are performed either after the failure of the equipment to restore it to the working condition or before any kind of failure to avoid the equipment or a part from any kind of failure. Maintenance contributes around 15-40 % of the total production costs. Maintenance strategy can be defined as the identification, researching and execution of repair, replace, inspect or servicing decisions or in short, the maintenance orders. Reactive Maintenance is one of the most common and widely used maintenance strategies. Reactive Maintenance focuses to restore the equipment to its normal operating conditions by repairing or replacing the faulty components and parts. Preventive Maintenance consists of periodic maintenance. Preventive Maintenance is carried after a specific operating hour, at calendar intervals or after a certain specified number of operating cycles. The intervals are based on the operating industry experience and the manufacturers' recommendations given in the manuals. It mitigates the degradation of the component or the equipment to sustain its life or even extending it. Total Productive Maintenance (TPM) is a maintenance philosophy that requires not only the employee's involvement but also the corporate management. It is a maintenance system, which is driven by the histories of the equipment and the statistics. The equipment histories are thoroughly analysed and room for improvements is found as equipment histories can lead to proactive maintenance approach. "5S" approach is the basis of total productive maintenance system.

Condition Based Maintenance (CBM) also called predictive maintenance, is a strategy in which maintenance work is performed when the condition of the equipment warrants10. In such a maintenance strategy or philosophy, the replace or repair work is performed before obvious problem occurs. It avoids unnecessary replacement of parts or components because it is purely based on the actual condition of the equipment. It needs periodic lubrication, testing and observing trends of the equipment failure or unhealthy events. Industrial Internet is the latest of all maintenance philosophies. Industrial Internet uses data analytics, data visualization, and mobile collaboration devices with user interfaces. It enables preventive maintenance based on the actual condition of the equipment or plant thus resulting in a zero-unplanned downtime. It can be dealt as the advance form of condition based maintenance. Pareto analysis helps in identify the vital breakdowns. It is based on 80-20 rule which states that eighty percent of the problems are caused by twenty percent of the factors. It highlights the major factors behind the problems that tend to focus factors. "Five Why" is another approach used for exploring root causes. It is a questioning method for analysis of the major problem. It focuses on the major forces behind the occurrences of the failure and to devise a plan or prevention method for the respective problems. It is a powerful tool used by professionals to find out the root cause of the failure. Once the root cause of the failure is found then the elimination can be planned.

III. FMEA ANALYSIS

Mining technology development has led to the development of complex technical systems that can hardly be seen without a systematic approach to analytical and methodological terms. Complex technical systems in the mining industry are the result of the growing interest in and need for resource potential. Analysis and risk management in the mining industry is a key factor in the quality and reliability management. One of the main problems present in the technical systems in the mining industry is to effectively analyse and manage risk? Until now, risk management did not give adequate importance. However, there is a real need and obligation for an urgent change in the situation. One of several possible alternatives in the context of risk analysis and the implementation of a system (FMECA and FMEA method) is to identify errors prior to their occurrence, which could position the real potential benefits in mining.

FMEA & FMECA, known as Failure Mode and Effects Analysis and Failure Mode Effects and Criticality Analysis, respectively, are a way for systems to be decomposed on a functional level. The loss of particular component function is considered to be a failure mode of the component. To use these methods, a system or component must be functionally decomposed. (Kumar Prakash & Srivastava R. K.)

FMECA is the most prominent and more widely used than FMEA, but is essentially the same method but yields a criticality instead of risk priority number for a metric. These methods consider a failure mode, its likelihood of occurrence, the severity of occurrence, and the likelihood of detection of the failure mode (observe-ability). The problem with the methods comes with the calculation of the severity or Risk Priority Number (RPN), which is essentially the likelihood (or number) of occurrences times the severity times the likelihood (or number) of detections. Failure modes with the highest RPNs are to be evaluated first. Although it is arguable that a more observable failure due to the ability to detect it may be prevented or mitigated more easily, RPNs are by no means a solid metric for weighing failures. There is no sane agreement from mathematically equating a highly unlikely, severe event with a highly probable, less severe event. FMEA/FMECA is generally beneficial at smaller levels of granularity- the micro scale, such as failure modes within components, rather than at the system level. These methods can also be beneficial in bottom-up (Inductive) FT generation, although FT's Department are typically generated from a top-down or deductive approach, which does not require the use of a supporting FMECA analysis. (Kumar Prakash & Srivastava R. K.)

Application Of Fmea

In the knowledge engineering phase: If we take the case of load haul dumper, however everybody is very much familiar with this. The knowledge engineering phase of this research involved the identification of the different main components and corresponding failure modes for LHD. These systems have some equipment associated with the sub-system. Through extensive research, relevant data were collected of all the possible failure modes. Such data were recorded on reliability centred maintenance analysis FMEA (Failure Mode and Effect Analysis) sheets.

SEVERITY		
Duration of service interruption(hours)	Criterion of severity	Value
>8	Very catastrophic	8
7	Catastrophic	7
6	Very serious	6
5	Serious	5
4	Medium	4
3	Significant	3
2	Minor	2
1	Very minor	1
0.5	Small	0.6
<0.5	Very small	0.2

Occurrence (O)		
Possible rate of occurrence	Criterion of Occurrence	Value
Once every 12 years	Failure near zero or no	1
Once every 10 years	Very low, failure isolation, rarely	2
Once every 8 years	Low, often fail	3
Once every 6 years		4
Once every 4 years	Average, occasional failure	5
Once every 2 years		6
Once every year		7
Once every 6 months	High, frequent failure	8
Once every month		9
Once every week	Very high, very high failure	10

(Sahoo T.K, Sarkar A.K., Sarkar P.K.)

IV. TECHNICAL ASPECT OF RISK ASSESSMENT

Research in fundamental process mining functionality of shows, reliability and safety of technical systems can hardly be achieved without the identification of all aspects of risk, or at least more, expert-level analysis, processing, and generate more solutions at the level of qualitative relations professional eligibility ceilings. Conducted research has focused technical aspects of risk analysis. Knowledge of state and behaviour of technical systems (excavator for surface mining and related equipment) is the main goal of diagnosis and an important reason for his constant monitoring online positioned critical areas. This approach allows the routing information from different fields in order to work with less parameters determine the real behaviour of the system, or whether his behaviour under load in real operating conditions in accordance with the prediction of the designer. (Kumar Prakash & Srivastava R. K.) The next step is to develop strategies reaction/response to the destruction in the context of recovery from the effects. Basic reasons why the relevant research and realized risk in the mining industry is: (1- complexity of technical systems in the exploitation of mining resources with critical and high-risk situation in a cancellation), (2- destruction/damage and large Multi-faceted technical

damage in mining, made in real time and space), and (3 - the potential criticality of the system due to the technical parts - cracks, crevices, vibration, wear and tear, hidden pipe cavities in castings, etc.).
Risk analysis, minimization and monitoring, manufacturing mining recognize the need for:
1. Development of methodology for systemic risk analysis of technical systems;
2. Developing a methodology for assessing the impact of all identified aspects of the destructive potential of technical systems in operation;
3. System analysis, needs assessment for partial or complete redesign and modernization;
4. Defining requirements and choice of technical risk management systems;
5. Configuration management process technical risks in mining;
6. Provide competent human resources for multidisciplinary work on risk management.
(Kumar Prakash & Srivastava R. K.)

V. RISK ANALYSIS USING FMECA METHOD

Analysis of the types, effects and critical failure (Failure modes, Effects and criticality analysis-FMECA) is a method of assessing risk based on consideration of their consequences for the work product. It is a systematic process that allows the definition of activities aimed at minimizing risk. The basic approach is to identify and describe each type of potential failure, which may jeopardize the purpose of the product. The analysis consists in the tabulation or graphical presentation of certain types of dismissal, in accordance with their consequences and causes, control measures (control and diagnostics), corrective measures (measure of compensation), the degree of criticism and other data relating to the design, manufacturing process, maintenance etc. Based on the results obtained using methods FMECA, corrective and preventive measures can be improved by designing determining ways of eliminating or lowering the probability of critical type of failure phenomena. However, the method of FMECA can be used as an effective tool not only in design but also for improving the production process and planning of preventive maintenance.

The essence of methods of FMECA is to identify and prevent known and potential problems with the products before they reach the user. To do this you need to make some assumptions, such as the problems that have different priorities. So, setting priorities is important for the breakthrough in the application of FMECA methods. There are three components that help define priorities related to the dismissals of products:
- ✓ Failure to appear;
- ✓ Weight and failure;
- ✓ Detection of failures.
- ✓ The frequency of occurrence of a failure.

Weight is the severity (seriousness of the consequences) of cancellation. Describing the ability of diagnostic failure before it reaches users. Based on the FMECA method it is possible to systematically identify and document the potential impact of individual failures on the successful functioning of the products, operator safety, results such as reliability, maintainability and performance products. Specificity FMECA method consists in the possibility grade products in various stages of its life cycle (design, manufacturing process,use maitntenance) in terms of ways in which problems (failures, errors. Conflicts,) can happen. (Kumar Prakash & Srivastava R. K.)

Calculation Of Risk Priority Number

Assessment of the degree of criticism (Risk Priority Number - RPN) for each pair of "possible type of failure-possible cause of failure types, can be deduced by the expression:

$$RPN = PF \times FDV \times PFR$$

Substrates PF, FDV and PFR are usually measured by grades 1 to 10 (can be used and other intervals). Thus estimated value of the degree of critical RPN is compared with previously determined values allowed RPN allowed. The solution is evaluated as satisfactory, if the RPN < RPN allowed, and if not, then the appropriate corrective measures provides the target. (SAHOO T, SARKAR P. K., SARKAR A.K.)

Criticality Analysis and Maintenance Strategy

Parameters of criticality analysis

Maintenance strategy selection problem is based on criticality analysis. It casts its shadow on numerous parameters for the criticality analysis. To name, they are Safety, Machine importance for the process, Cost of maintenance, frequency of failure, Total downtime length, Operating conditions, Availability of the spare parts/machines, Difficulty in accessing, propagation effect and Production loss cost. Moving onto the best of them, six parameters have been made the scanner for the subsequent analysis purposes of the failure components. The analysis is an extension of FMECA technique.

Following six parameters of criticality analysis being:

- Safety
- Machine importance for the process
- Cost of maintenance
- Frequency of failure
- Total downtime length
- Operative conditions

Weight values are required to assign to the relevant parameters considered in FMECA. The six parameters presented above derived from an accurate pre analysis of the 12 criteria to select of all relevant parameters that can contribute to the machine criticality. It is also maneuvered to restrict the complexity associated with the analysis to be performed, number of parameters is reduced for evaluation by grouping together similar factors. Because, as the number of parameter increases, complexity also increases tremendously but that does not guarantee a higher degree of accurate analysis, as anticipated beforehand. Besides, the quantitative evaluation of factors described is complex and subject to risk of incorrect estimates.

The following clusters were created. The "spare machine availability" mainly affects the duration which are generally uninterrupted production process and can therefore be linked to the "importance of machine for some particular processes" which includes the "lost production cost". In terms of spare parts, the "maintenance cost" can include the type of machine maintenance and manpower contribution which can be clustered with the "total downtime length" specifically. "Safety system", "frequency of failure" "access difficulty" and "operating conditions" are considered to be standalone factors by maintenance staff.
(Kumar Prakash & Srivastava R. K.)

Criticality Analysis of Equipment:
Weight values assigned to the relevant parameters considered in FMECA analysis

Weight of parameter

- Safety – 1.5
- Machine importance for the process – 3
- Maintenance costs – 2
- Failure frequency – 1.5
- Downtime length – 1
- Access and difficulty & operating condition – 1

Criticality Index: - The factors taken into account are grouped together in following criticality index (C.I),
C.I = (S x Weight Value of Safety) + (IP x Weight value of machine importance) + (MC x Weight value of maintenance costs) + (FF X Weight value of failure frequency) + (DL x Weight Value of downtime length) + (AD x Weight Value of access difficulty).

- Where S = safety, IP = importance of machine for the process, MC = maintenance costs, FF = failure frequency, DL = downtime length, AD = machine access difficulty.

Table : Probability of Occurrence Criteria for Ranking Failure Modes

Probability	**Unlikely**	**Remote**	**Infrequent**	**Occasional**	**Likely**
Description	Failure under These Circumstances is unlikely	Failure is Highly Improbable due to lack of Relevant circumstances	Failure could occur under rare and Extreme Circumstance	Failure probable in response to intermittent, extreme but foreseeable events	Failure is Almost inevitable and Possibly Frequent
Frequency of					

occurrence in the 19 year mine-life	0	0-1	1-2	2-4	Annually

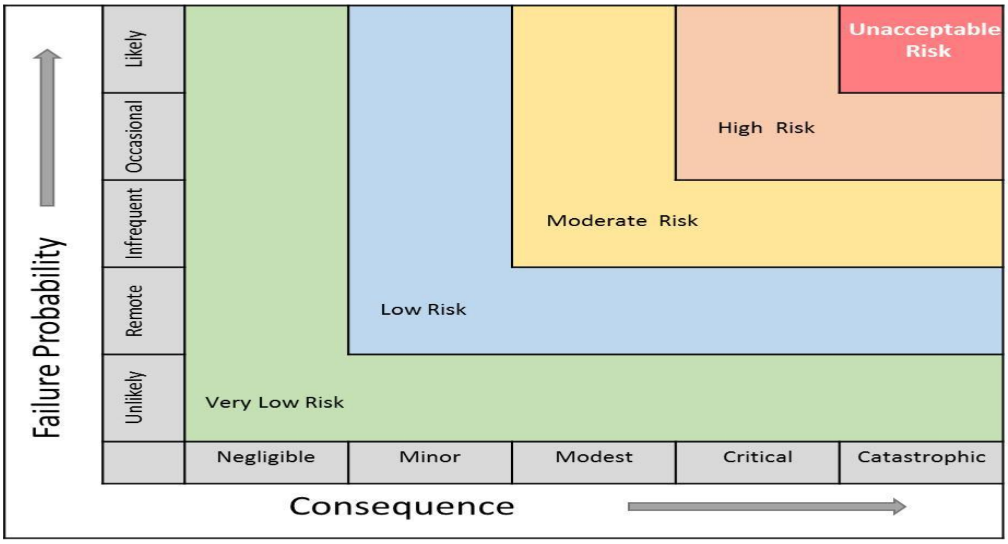


Table : Consequence Criteria for Ranking Failure Modes

Consequence	**Negligible**	**Minor**	**Modest**	**Critical**	**Catastrophic**
Defined	No significant Affect	Minor effect on environment, human health, or project Viability	Measurable effect on environment or human health resulting in intermittent or temporary operational changes with modest financial consequence	Measurable effect on environment or human health resulting in continued operational changes with significant financial consequence	Overwhelming effect on environment and human health resulting in shutdown and financial consequence affecting project viability
Environmental risk	No environmental Risk	Transient, minor upset requiring operational response, no design or treatment response Required	Impact which can be readily addressed through minor design or treatment action	Impact which can be addressed through long term design or significant treatment action	Impact requiring major facility redesign or rebuild, requiring prolonged effort
Human health risk	No human health Risk	No injuries	Possible minor injuries	Injury, no fatality	Injuries with fatalities
Resulting change in operations	No changes Required	Maintenance action Only	Short term loss of facility in operation requiring minor	Prolonged delay in facility operations requiring major reconstruction, may result in agency	Complete loss of function requiring facility replacement or loss of project

			reconstructions; other resources available	initiated temporary suspension of operations	viability, suspension of mine Permits

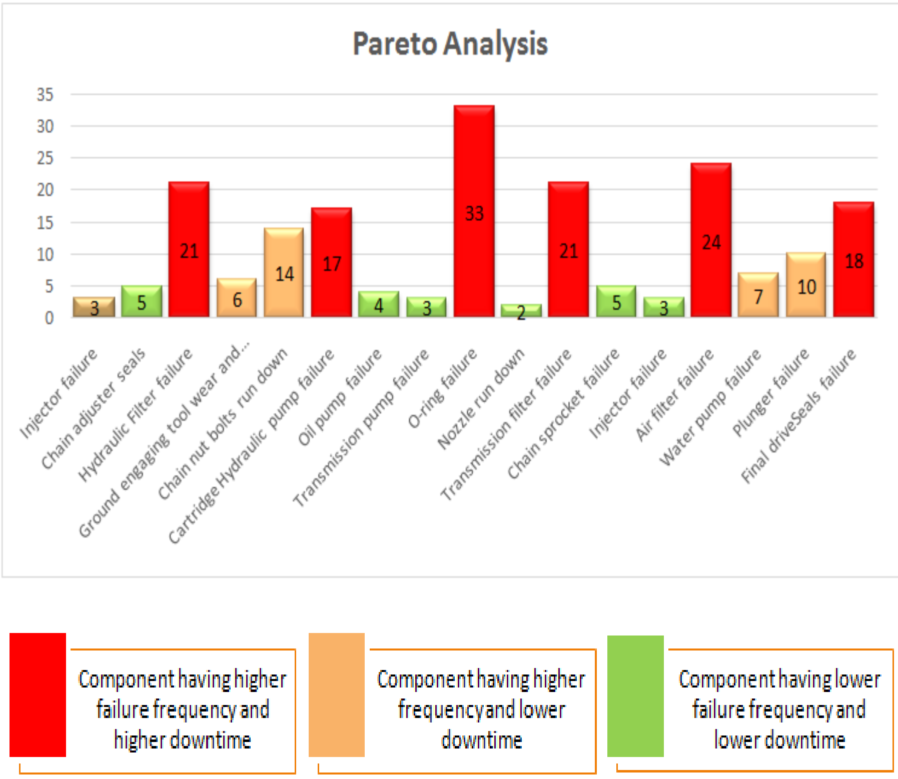
Failures Associated With Excavator

It is based on the criticality analysis and the parameters considered in it, that has produced 16 failure modes, and accounted for necessary and required productivity loss. Subsequently, Pareto analysis has been conducted and the results of the same has a lot more to say on the most critical causes and frequency of failures as well. Different failures, which has been culminated are listed below: -

Injector failure

- Chain adjuster seals failure
- Hydraulic filter failure
- Ground engaging tool wear and tear
- Chain nut and bolt rundown
- Cartridge (hydraulic pump) failure
- Oil pump failure
- Transmission pump failure
- Nozzle run down
- Transmission filter failure
- Chain sprocket failure
- Injector failure
- Air filter failure
- Water pump failure
- Plunger failure
- Final drive seals failure

(Ullah Anwar, Islam Sabir, Khattak Sikandar Bilal, Rehman Safi Ur, Maqsood Shahid, Ullah Misbah, Akhtar Rehman, Nawaj Rashid**)**



FAILURE MODES	CAUSES	PROBABILITY	CONSEQUENCE	PROPOSED SOLUTION	REVISED PROBABILITY	Revised Consequence
		UNMITIGATED			MITIGATED	
O-Ring Failure	1.High Pressure 2. Weak Metallurgical Property 3.Larger Clearance Condition	Frequent	Catastrophic	1. Back Up Devices Into Action. 2. Temperature Exposed Is To Be Kept Minimum. 3. Low Set O-Ring Material To Be Used.	Remote	Critical
Hydraulic Jack Seals	1. Filthy Condition 2. Open To External Surroundings	Frequent	Very Critical	1.Proper Lubrication And Cleaning Action, 2. Proactive Inspection Prior To Use. 3.Piston And Rod Retracted When Not In Use.	Unlikely	Modest
Air Filter Failure	1. Filthy Condition	Frequent	Critical	1. Replacement Of Air Filter Periodically 2. Air Filter Should Be Cleaned Prior To Use. 3. Protection From Contaminant Liquid.	Unlikely	Critical
Hydraulic Filter	1. Mixing Of Water And Oil 2. Oil Contamination Due To Particulates	Remote	Critical	1. Periodic Inspection. 2. Replacement Of Filter At Regular Interval.	Likely	Modest
Final Drive Seals Failure	1. Oil Contamination 2.Changing Filters Irregularly 3.Sillicon And Water	Remote	Critical	1. Oil Filters To Be Changed Regularly. 2. Oil Use Efficiently And Properly.	Unlikely	Minor
Cartridge Failure	1.Hydraulic Fluids Adulteration, 2. Contamination Of Solid Particles	Remote	Modest	1. Replacement Of Complete Fluid When Contaminated. 2.Hydraulic Filter To Be Changed At Periodic Intervals.	Unlikely	Modest
Transmission Filter Failure	1. Clogging Fluids. 2. Low Fluid Levels. 3.Transmission Slip	Infrequent	Catastrophic	1.Filter Change When Problem Surfaced. 2. Fluid Inspection.	Likely	Catastrophic

The above table shows unmitigated components criticality as well as mitigated positive outcomes. One thing that is very obvious to note here is that there are some proposed solutions to guide through the problems and mitigate the unmitigated severe problems.

These proposed solutions, if implemented properly, can give better outcomes in terms of proper functioning as well as better full capacity utilisation of the hydraulic excavator. The advanced maintenance management strategy proposed after calculation of the Risk Priority Number is also a very important analysis. Definitely it is impossible to protect the degradation of the equipment or machinery, and that too in the case of mining machinery which are way too heavy to cost the functioning of the excavator components at faster rate. It becomes essential for the maintenance engineer to suggest some strategy or technique to slow down the depreciation of the same, and in this way we can reserve the life of the machine. If the proposed maintenance strategy is carried out as planned, it will be more easier to utilise the same to its full capacity.

Calculation Of Rpn And Decision On Maintenance Strategy

Sl. No.	Name	Severity	Occurrence	Detectibility	Risk Priority Number	Maintenance Strategy
1	O-Ring	6	8	7	336	Predictive Maintenance
2	Hydraulic Jack Seals	4	7	5	140	Corrective Maintenance
3	Oil Filter	5	7	5	175	Corrective Maintenance
4	Transmission Filter	8	6	6	288	Preventive Maintenance
5	Hydraulic Filter	6	7	6	252	Preventive Maintenance
6	Chain Sprocket	3	5	6	90	Corrective Maintenance
7	Cartridge Failure	5	4	5	100	Corrective Maintenance
8	Oil Pump	4	4	6	96	Corrective Maintenance
9	Air Filter	6	8	4	192	Corrective Maintenance
10	Nozzle Run Down	3	2	3	18	Corrective Maintenance

As mentioned in the previous pages, 17 modes of failures have been categorised. They have been put down to the testimony under the Pareto analysis so as to be aware of the frequency of the failures associated. Afterwards, only 7 highly critical components have been sorted out for FMEA/FMECA analysis. The failures modes along with causes, unmitigated & mitigated probability and consequences with probable solutions have been proposed in the analysis. Only those components have been investigated whose downtime length or Failure rates or both are quite significant in context of desired performance of excavator. O-rings fail frequency is large followed by jack seals and has been proposed for the predictive and corrective maintenance respectively.

VI. Conclusions

An advanced system for maintenance strategy for mining excavators has been developed. These mining excavators are increasingly being used in open cast mining. The monitoring and control system has equipment database obtained from manufacturers and mine specific data are entered into the system. (Adhammar Et.al, Kumar Prakash, Srivastava R.K.) The paper has FMEA/FMECA analysis of components failure detection and system related failures and accordingly databases are formed by the FMEA and FMECA which predict fault or deterioration in excavator components. The main aim is to select the best maintenance strategy to reduce the maintenance related cost as well as to reduce the unit production cost in mining sector. In the paper, related data have been collected and then based on the criticality analysis several failure modes have been shortlisted, and then Pareto analysis conducted shows various failure frequency. Post Pareto results, FMEA/FMECA analysis of most critical components (8 components) have been carried out, which culminates with unmitigated and mitigated criticality status along with the proposed solutions to redress the problems. This same helps in lowering down the failure rate or frequency of the components. The calculation of Risk Priority Number (RPN) and the suggested maintenance strategy aids in lowering the downtime length of the failure. Therefore, the paper deals with both the major concerns i.e. failure frequency as well downtime length/durations. The analysis was used to identify and then propose the mitigation to more typical mine planning in order to enhance the productivity in mining manoeuvers. The analysis documents the incorporation of these mitigations consistently and significantly reduces the risk of failure. The same shows the selection of improved process, and incorporation of improved changes in construction and design methods.

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