MAINTENANCE SYSTEM FOR HEAVY EARTH MOVING EQUIPMENT

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ABSTRACT

Heavy earth moving equipment's are critical for completion of any developmental projects. Dams, schools, bridges or any mining related initiations are part of these infrastructure development projects. Usually the delays are due to the inefficient and ineffective maintenance procedures of the heavy earth moving equipment's. Poor record keeping and un-systemized maintenance procedures leads to reducing the machine effective life cycle. To avoid catastrophic losses in production and, market share, a maintenance model for such equipment is developed. Heavy equipment availability is mandatory on site. Their movement is critical and usually limited. The data collected includes both manufacturer and operator requirement. Usually such equipment is treated as normal machine irrespective of the rough environment it works in. The analysis includes segregation, Pareto analysis and Five Why analysis. A dedicated maintenance model is proposed which includes checklist and proper maintenance schedule.

KEYWORDS: *Maintenance, Total Productive Maintenance, Conditioned Based Maintenance, Industrial Internet, Maintenance Prevention, Heavy Earth Moving Equipment, Checklist.*

INTRODUCTION

Heavy Earth Moving Equipment (HEME) refers to heavy-duty vehicles designed for executing construction tasks mostly involving earthwork operations. Most of the heavy-duty equipment uses hydraulic system to perform such operations and motions. It is widely used in construction and mineral industry. Due to the high failure rate, higher cost of maintenance and extreme competitiveness of the industry, one has to think for out of box solution. Effective maintenance system for the HEME is one the solution. This has a real competitive advantage in controlling losses associated with the downtimes and the emergency equipment repairs.

Most of the industries focus their maintenance procedures or practices mainly on the reactive or emergency repairs. Having own equipment is considered to be the critical asset of an organization[1]. If these failures are anticipated correctly and prevented, the company can remain in competition for a longer time. Enjoying the benefits of decreased maintenance costs which leads to increased profit margins and minimum downtimes. The high rate of failures is not tolerated for HEME because they are the backbone of an industry. It has a potential to endanger the future of the firm leaving the firm or industry behind its competitors. Effective maintenance system avoids the catastrophic losses that endangers the industry's reputation and achieves maximum availability and productivity[2]. The purpose of this research is to study the system and develop a maintenance system that fits the industry. To make a firm's equipment available for maximum operations and reduce its maintenance costs. Industry that lacks effective maintenance policy faces issues like non-availability, higher downtimes and higher maintenance costs.

LITERATURE REVIEW

Maintenance means the work of keeping equipment or anything in proper condition[3]. 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[4]. Maintenance strategy can be defined as the identification, researching and execution of repair, replace, inspect or servicing decisions or in short the maintenance orders[5]. Reactive Maintenance is one of the most common and widely used maintenance strategies. Reactive Maintenance focuses to restore the equipment to its normal operating

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conditions by repairing or replacing the faulty components and parts[6]. Preventive Maintenance consists of periodic maintenance[7]. Preventive Maintenance is carried after a specific operating hours, at calendar intervals or after a certain specified number of operating cycles[8]. 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 analyzed 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[9]. Condition Based Maintenance (CBM) also called predictive maintenance, is a strategy in which maintenance work is performed when the condition of the equipment warrants[10]. 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[11]. 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[12]. 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[13]. 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[14]. It focuses on the major forces behind the occurrences of the failure and to devise a plan or prevention method for the respective problems[14]. 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 easily.

METHODOLOGY

First a preliminary literature survey is carried out to understand the maintenance system of HEME. A problem statement is developed which says that most companies faces higher unplanned downtimes because of the neglected maintenance operations. Companies mostly follow corrective maintenance strategy that ignores inspections and preventive checks. The literature survey is done to attain knowledge of the different maintenance strategies currently used worldwide. This led to the deduction of performance parameters identification such as Availability and Mean Time Between Failures (MTBF). The latest techniques used worldwide to reduce the unavailability and downtime is reviewed. The performance parameters are verified in discussion with the project supervisory team. For progress in this research, it is necessary to select a firm for reviewing and proposing maintenance system. For this purpose M-Construction Company is selected which is a Khyber Pakhtunkhwa, a province of Pakistan, based company. For data collection interviews are arranged with the maintenance personnel. The staff is thoroughly questioned about the existing system. There is no in house maintenance department so the maintenance operations are out sourced. The maintenance firm is contacted and questioned regarding maintenance problem. It is concluded that M-Construction uses corrective maintenance and neglects inspection and monitoring of equipment. The data related to the annual maintenance and equipment failure is collected. The data is extracted from the maintenance books. The extracted data is fed into the excel sheets to calculate the failures frequency. Downtimes and MTTR is assessed. The analyzed data is segregated on three different criteria. First segregation is based on costs, second on likelihood and third on severity. This gives an input for prioritizing critical problems. Pareto Analysis is done for the segregated data to identify recurring problems. This narrows down the attention from a pool of failures to some most important ones. The results are used as an input to Five Why analysis. The problems are questioned two times each to find root causes behind the failures. If any failure occurs its root cause is removed and documented.

DATA COLLECTION

Documentation and record keeping of the maintenance problems is a tardy job for every organization, so is with the M-Construction. Visits and interviews are arranged to collect the data. The collected data is related to excavators that are used in the construction firm for earth removal, and digging operations. Table 1 shows all the major excavator problems that the firm faced in previous year.

The finding of the keen observation and interviews is that the company follows reactive maintenance strategy. No pre-failure studies are available to prevent the incipient failures or breakdowns. Upon the failure, the maintenance crew is called for fixing. The maintenance method employed by the firm is shown in Figure 1.

Mandatory things like oil change and lubrications are done periodically. When a failure occurs, the company after confirming non-operability of the equipment asks the maintenance team to fix the problem. Most of the time operators do not understand and has no failure history logs.

Table 1. Excavator Failures

Maintenance Problems	Maintenance Method Used
O-rings failure	Corrective maintenance
Hydraulic jack seals failure	Corrective maintenance
Oil filter failure	Corrective maintenance
Hydraulic filter failure	Corrective maintenance
Transmission filters failure	Corrective maintenance
Hydraulic pump failure	Corrective maintenance
Transmission pump Failure	Corrective Maintenance
Chain Sprocket failure	Corrective Maintenance
Chain Bolts failure	Corrective Maintenance
Cartridge failure	Corrective Maintenance
Oil Pumps failure	Corrective Maintenance
Injectors failure	Corrective Maintenance
Final drive seals	Corrective Maintenance
Water pumps failure	Corrective Maintenance
Chain adjuster seals	Corrective maintenance
Diesel pumps plunger run down	Reactive maintenance
Nozzles run down	Reactive maintenance
Air Filters failure	Reactive maintenance
Ground Engagement tools	Reactive maintenance

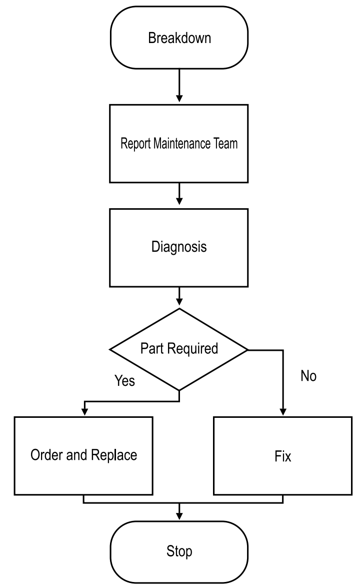

Figure 1. Current maintenance system

During data collection it is reported that the firm uses substandard oil and spares. Not only this causes frequent failures but also reduces equipment life. This directly leads to higher maintenance cost.

The data collection concludes that hydraulic problem, under carriage problems and engine problems are the most vital ones.

DATA ANALYSIS

Analysis of the data is necessary to set the priorities of the maintenance works and highlight the major problems that contribute the most. The analysis targets the improvement areas and the areas subject to major failures and downtime. Once the areas of the improvement are finalized then one can setup a system that can reduce the overall downtimes and unavailability of the equipment. Segregation gives the freedom to set priorities and to find the areas of improvement. Likelihood of the problems identified previously in the data collection phase. Likelihood criterion is selected to segregate the identified problems. Figure 2 shows problem segregation on the basis of likelihood. An O-ring failure with a frequency of 33 is the most significant factor. Followed by hydraulic jack failure. Nozzles run down is the least significant factor.

Pareto analysis is used to identify problems. The overall contribution of the vital problems is highlighted by calculating percent impact of individual problems. Figure 2 shows that O-ring failures, Hydraulic jack seals failure, Air filter failure, Hydraulic filter failure, transmission filter failure, final drive seals failure, cartridge failure, and track chain nut-bolts loosening contributes significantly to overall downtime.

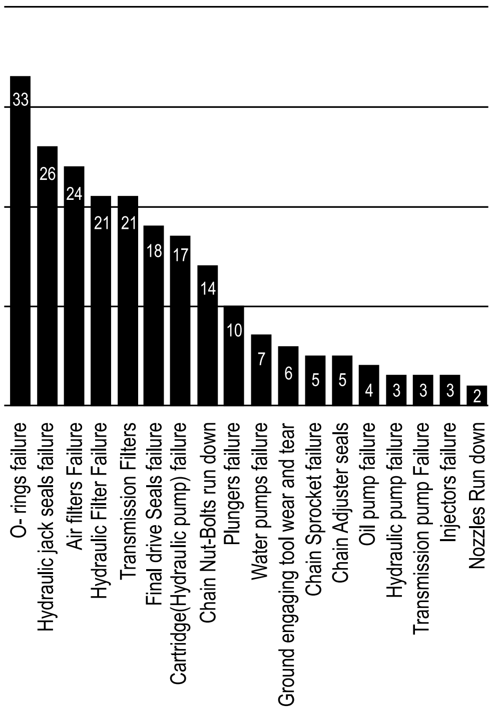

Figure 2. Frequencies and Maintenance Problem

Five Why Analysis (FWA) focus on the major forces responsible for failure. It helps in devising a plan for prevention method. It is a powerful tool used by professionals to find out the root cause of the failure.

Table 2 gives an insight view of how the FWA is performed at initial stage. Hydraulic failure may occur due to dirt, lubrication or seal wear. The dirt cause as shown in Table 3 can be due to dusty working environment, no proper prior cleaning or due to no dirt safeguards. The same procedure is adopted for all the vital problems.

RESULTS AND DISCUSSION

The availability and operational verification of the new

Table 2. Five Why Analysis

S.No	Problem	Reasons of problem(Why 1)
1	O-rings Failure	1. Extrusion
		2. Compression Set
2	Hydraulic Jack Seals failure	1. Dirt
		2. No lubrication
		3. Off- Center loads
		4. Wear in seals
3	Air Filter Failure	1. Dirt
		2. Interval of change elongation
4	Hydraulic Filter Failure	1. Interval of change elongation
		2. No inspection
		3. Dirt
5	Transmission Filters Failure	1. Dirt
		2. Clogging or obstruction
		3. Elongation of changing intervals
6	Final Drive Seals	1. Contaminated oil
		2. Changing filters irregularly and lately
7	Cartridge Failure	1. Low quality hydraulic fluids
		2. Contamination

Table 3. Second iteration of Five Why Analysis

Reasons of Why 1
1. Excessive clearances. 2. High pressure 3. Selection of O-ring material with inherently poor compression set properties. 4. Incomplete curing
1. Exposed to dirt 2. No cleanliness 3. Open to environment after use
1. No cleaning daily 2. Dusty condition of workplace
1. Contamination in oil, particulates 2. Water in oil
1. Dirt or contamination in fluids/ oil
1. Silicon, water 2. Muddy water
1. Water and silicon in hydraulic fluid 2. Solid particles

Table 4. Critical problems w.r.to Likelihood factor

S. No	Maintenance Problems	Frequency
1	O-Rings Failure	33
2	Hydraulic Jack Seals Failure	26
3	Air Filters Failure	24
4	Hydraulic Filters	21
5	Transmission Filters Failure	21
6	Final Drive Seals Failure	18
7	Cartridge Failure	17

model or proposed solution cannot be measured without proper inputs specifically the downtime calculation considering the planned as well as unplanned downtimes. The subject firm does not keep any maintenance records so validation of the model is not possible on quantitative basis. Only the benefits of the new proposed system over the current system can give us the deducted results. The current system uses reactive maintenance to keep the equipment in operable condition while the proposed system takes into consideration the data keeping, spare parts inventory, continuous monitoring, real time data in form of PID's and other techniques like Five Why Analysis & Pareto Analysis to cope with the problems. Critical problems with respect to the likelihood of occurrences are found from the segregation of data on the basis of frequency. In this section the frequency of each failure is taken into the account so that the impact of each maintenance problem is calculated. The maintenance problem that has higher rates of occurrences is termed as critical. Table 4 shows the most critical problems.

The most recurring problems are determined through Pareto analysis. This results in some distinct failures, which have highest frequencies of occurrences. It is deduced that the probability or chances of occurrences of these problems are high. This makes sense to devise prevention methods to these problems and eliminate frequent failures. The prevention methods for the most recurring problems are shown in Table 5. Using the knowledge of the root cause behind the failure, a prevention method is devised. These methods are discussed with Heavy Equipment Maintenance experts for verification.

1. Proposed maintenance model

The firm should not overload equipment. It is reported that different brands of lubricants are blended to save

Table 5. Prevention Methods for most recurring problems

Problem	Prevention Method
O-rings Failure	• Decrease clearance by reducing machining tolerances.
	• Use back-up devices.
	• Use "LOW-SET"O-ring material whenever possible.
	• Reduce system operating temperature
Hydraulic Jack Seals failure	• Keep piston & rod retracted when not in use
	• Visually inspect before each use
	• Properly lubricate and clean
Air Filter Failure	• Clean air filter before using equipment
	• Periodically replace air filters without delay
Hydraulic Filter Failure	• Periodically replace Hydraulic filters without delay
	• Inspect periodically
Transmission Filters Failure	• Inspect transmission fluid periodically
	• Change filters on time
Final Drive Seals	• Proper oil use
	• Replace oil on time at regular intervals
	• Change oil filters regularly
Cartridge Failure	• Inspect fluid for contamination
	• Regularly change hydraulic filter

cost. This in long run deteriorates equipment life. The firm should stop such practices. Moreover the fuel is stored in galvanized container that is against the standard operation procedure for storing fuel. The lubrication and over hauling schedule set by manufacturer should be followed strictly.

Keeping in view the attribute of Likelihood of failures. A system is suggested. It is hybrid maintenance system to cope with problems of unplanned downtimes, higher costs and frequencies. Combining the different principles is more effective than to apply a single strategy. Every strategy has its pros and cons, thus the combo is more effective and efficient to eliminate the problems. The proposed maintenance system is depicted in Figure 3.

Data from Engine Control Unit (ECU) give the parameter identifiers data that is used to determine the

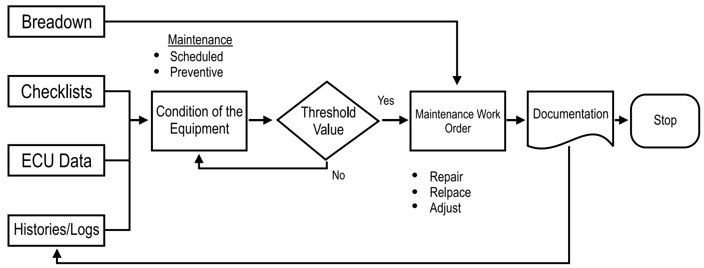

Figure 3. Proposed maintenance model

condition of the equipment. For example temperature of the engine oil can be determined through PID's. In parallel historical data is used from the database to project the failure trends and find out the probable time of failure. When the failure is most likely to occur, a maintenance order is issued. Manual data also act as an input to the system for certain replacements, inspections and checking. Once the condition of the equipment i.e. the real time data from the equipment through PID's is gathered then it is matched with the threshold value. Threshold value is different for different parameters. It is the level at which the equipment can withstand the situations. After matching of PID's values with the equipment threshold values the decision related to maintenance order is decided. If the maintenance order is issued, the job and maintenance order is added to the database which will be used in future to trend failures.

CONCLUSION

Use of HEME is not restricted to mining and construction industries. Most of the companies go for reactive maintenance program because it requires minimum staff and investments. Due to lack of in-house workshops and maintenance personnel the firm usually sub-contracts the maintenance services. Organization ignores proper maintenance programs and thus investments in maintenance programs are discarded. Sub-standard parts are given priority due to the cost factor. Data keeping, load capacity and condition of the equipment and field conditions are ignored. The M-Construction Company does not invest in any kind of maintenance program. Maintenance services are sub-contracted to other firms. M-company opts for reactive maintenance upon failures and neglects the equipment and field condition. Proper process for equipment inspection and lubrication is missing. Segregations of the failures yielded in critical problems. The prominent critical component is O-ring with a frequency of 33. The proposed maintenance model is focused on problem reduction with the help of proper check listing of different parts and data keeping. Condition of the equipment is valuable for the new proposed model. Equipment condition is taken into consideration for releasing maintenance work order.

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