29. IoT Based Maintenance for Mine Hydraulic Excavators

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ABSTRACT

Maintenance problems in mining equipment are considered as ill-structured problems for which effective algorithmic results are not possible due to lack of unknown nature of failures and mine conditions.

In general, maintenance methodologies focus on equipment failure in terms of breakdown. Majority of the maintenance optimization models are, in general, considers a fixed value of the cost of breakdown maintenance. But, the cost of breakdown maintenance not only includes down time losses and repair/replacement cost, but may also include various indirect cost. Prior detection of faults represents the most effective way to reduce the breakdown but the existing Indian scenario in terms of machine maintenance reveals the predominance of breakdown maintenance culture in the coal mining industries in particular and industries involving heavy duty earth moving machinery in general.

Various predictive maintenance systems have been used in coal mining industries to support engineering design and decision making. Its availability can be found in various mining parameters such as geological condition, mining condition, dig-ability assessment. Many researchers worked in the area of cost optimization in mining operation through IoT techniques. Advanced fault diagnosis methods have also been used in various research works such as model-based approaches, knowledge based approaches, qualitative simulation, neural network, genetic algorithm and classical multivariate statistical techniques.

But, very few models focus on the investigation of preventive replacement or a perfect planned maintenance policy or total productive maintenance policy that restores the equipment to an as-good-as-new state through IoT.

Keywords— *Mine Excavator, Failure & Maintenance optimization model, IoT.*

INTRODUCTION

A. DEVELOPMENT OF AN IOT SYSTEM

For efficacious detection of fault and trouble shooting in machines of mining industries, a relatively new programming approach in the form of Artificial intelligence (AI), in particular, knowledge-based systems (KBSs) is available which is being used in maintenance programs of mine equipments from common malfunctions to rarely emergency situations.

For effective maintenance methodologies, various fault detection techniques are used. For these techniques, systems are capable of utilizing human knowledge and tracing the complicated relations between different signals and possible results as experts do, so the same can be used in the mining industries too.

The software and database are used to overcome the difficulties of selecting the proper maintenance techniques. The precise diagnosis is carried out based on the different statistical analysis of the failure data. The relationship between the critical values of the component and various failures data are analyzed using expert knowledge. This knowledge is addressed by frames. By using this knowledge source, algorithm is developed for the process of inference.

The paper discusses an IoT framework for failure detection and predictive maintenance system being designed and developed. The proposed approach integrates conventional failure techniques with heuristic techniques derived from expert knowledge and different manuals to generate a prediction model of each component's failure. Detection of fault is performed by monitoring various parameters of excavators and assessing the measured and estimated data for abnormalities.

Categorization and location of the fault source is performed by the event and fault locator. If a component is the source of the fault, the predictive maintenance functionality is activated to assess the fault. The equipment is categorized in three categories based on the criticality, failure frequency and down time length. Assessment of the present conditions of equipment is performed using techniques which range from computer driven instrumentation (gauges, sensor etc) to human sensing to augur failure and to economically perform maintenance only when a potential failure is identified and at a time convenient to the production schedule.

The advantage of IoT include: reduction in machine down time, reduction in skill level for maintenance activities, ease of maintenance, speedy response and affordable cost. The reliability of diagnosis is highly dependent on the accurate information and past data. This study dealt with the design and development of a knowledge-based system for the evaluation of mining equipment in terms of fault diagnosis.

The method is more effective as it is designed to responds creatively like a human expert in unusual circumstances and can automatically modify its knowledge base as data is continuously and periodically monitored, and selected data is stored in the database. So, it can adjust existing rules or add new ones as the situation comes. It has extensions facility to provide interfaces to algorithmic programs.

The economic merit of particular IoT systems for condition based maintenance is obvious. It reduces frequency of breakdowns of critical components resulting in fewer work interruptions which has positive correlation with higher productivity in mines. The condition-based maintenance, if administered properly through AI, can prevent failures and also increases the availability of the equipment.

B. STAGES OF DEVELOPMENT

- Different techniques like Statistical Analysis, FMEA, FMECA, Fault Tree Analysis, Pareto Analysis and criticality analysis were used in order to develop this IoT system.
- Genetic Algorithm has also been used to make inferences, based on the acquired information (real time data) and the knowledge base, which further help to decide the suitable maintenance strategies in different situations.
- IoT system, based on wide range of fault diagnostics methodologies has been developed. While designing an IoT maintenance system, performance of these methodologies was verified using mining statistical data.
- For the development of this system, the standardization of the failure codes were classified. The critical components were identified and codes were given to the individual faults. Analyses were done through of the failure history analysis, maintenance manuals, and the expert knowledge. The rule base (algorithm) has been constructed and based on these algorithm program was written.
- For developing this particular Maintenance System, JAVA programming language has been used to make it "user friendly" and serves as a trouble-shooter.
- The similar methodology can also be used for different equipment

PARETO ANALYSIS

Pareto analysis can be applied by counting the number of defects for each of the different possible causes of poor quality in a product or services and then developing a frequency distribution from the data. The frequency distribution, referred to as a Pareto diagram, is an important visual assistance for attaining on major quality problems. Or in terms of maintenance management, a large majority of failures (80%) are produced by a very few reasons (20%).

A. USE OF PARETO CURVE IN RELIABILITY IMPROVEMENT

Pareto principle when applied to reliability, states that a majority of the failures may be diagnosed to only a small proportion of the many possible causes. These ‘vital few’ out of several causes are identified for tackling the problem to show significant result. ‘Pareto analysis’ indicates that factors leading to majority of the defects may be relatively few.

B. PARETO DIAGRAM

A Pareto diagram is a special type of histogram that helps us to distinguish and prioritize problematic areas. The Pareto diagram may involve data collected from data figures, maintenance and repair data, scrap rates of components or other sources. By identifying types of nonconformity from the relevant data sources, the Pareto diagram directs attention to most frequently occurring element. The diagram helps us to identify the root causes of the problems. Availability of relevant and reliable data determines the quality of the analysis.

Hence, the application of the Pareto analysis in maintenance management facilitates to focus on those failures which have the most impact on the maintenance strategies.

Tabel 29-1 Critical Components of Hydraulic Excavator EX 1200D (Troubleshooting A)

Sl. No.	Name of the component	Failure % age/ Year	Down Time/ Break down Hours	Mandatory Service	
				(1200 Hrs)	(2400 Hrs)
1	EC Sensor	3.9	04		Y
2	Boom Angle Sensor	3.1	06	Y	
3	Oil Temp Sensor	3.6	04		Y
4	Swing Parking Valve	0.4	03	Y	
5	Transmission Swing	2.8	08	Y	
6	Front Swing Pilot Valve	3.4	04	Y	
7	Travel Pilot Valve	0.9	02		Y
8	Roll In Pilot Pressure	3.2	04		Y
9	Pilot Shut Off Valve	0.7	04		Y
10	Intercooler	0.2	02		Y
11	Oil Cooler Fan Motor	1.9	12		Y
12	Front Idler	0.3	02		Y
13	Front Piping	0.8	04	Y	
14	Lubricating Piping	0.5	03	Y	
15	Pump Delivery Pressure	3.5	16		Y
16	Engine Control Dial Gauge	3.1	08		Y

Table 29-2 CRITICAL COMPONENTS OF HYDRAULIC EXCAVATOR EX 1200D (TROUBLESHOOTING B)

Sl. No.	**Name of the component**	**Failure % age/ Year**	**Down Time/Break down Hours**	**Mandatory Service**	
				1200 Hrs	**2400 Hrs**
1	Swing Motor	1.8	12		Y
2	Swing Bearing	3.1	09	Y	
3	Swing Control Valve	3.6	06		Y
4	Arm Assembly	1.6	12		Y
5	Boom Cylinder	2.4	16		Y
6	Main Control Valve	0.7	12		Y
7	Signal Control Valve	1.1	04	Y	
8	Front Attachment Pilot	0.4	04	Y	
9	Spool Valve	2.1	10		Y
10	Pump Control Valve	2.7	12		Y
11	Pump device Cylinder	0.8	08	Y	
12	Oil Cooler Unit	0.1	08		Y
13	Auto Lubrication Device	1.9	06	Y	
14	Track Adjuster	2.3	20	Y	
15	Upper Roller	3.2	08		Y
16	Lower Roller	3.9	12	Y	
17	Accumulator	0.5	08	Y	
18	Wiper Unit	3.3	02		Y
19	Actuator System	3.5	20		Y

Tabel 29-3 . CRITICAL COMPONENTS OF HYDRAULIC EXCAVATOR EX 1200D (TROUBLESHOOTING C)

Sl. No.	**Name of the component**	**Failure % age/ Year**	**Down Time/Break down Hours**	**Mandatory Service**	
				1200 Hrs	**2400 Hrs**
1	Monitor	3.4	06		Y
2	Air Conditioner Condenser	0.5	04		
3	Air Conditioner Control Panel	1.2	06		
4	Coolant Temp. Sensor	1.8	06	Y	
5	Coolant Level Indicator	3.1	08		Y
6	Coolant Temp. Gauge	3.7	08		Y
7	Overheat Indicator	3.6	04		Y
8	Preheat Indicator	3.2	04		Y
9	Engine Oil Pr. Indicator	3.3	01		Y
10	Engine Oil Level Indicator	3.7	01		Y
11	Air Filter Restriction Indicator	3.9	01	Y	
12	Exhaust Gas Temp Indicator	2.4	04		Y
13	Buzzer	3.9	01		
14	Buzzer Cancel Switch	1.1	02		
15	Transmission Oil Pr. Switch	3.4	01		
16	Pilot Pressure Sensor	2.1	04		
17	Hydraulic Oil Temp Sensor	3.1	04		Y
18	Battery	0.1	01		
19	Starter Relay Battery Relay	1.2	04		
20	DC-DC Converter	3.2	01		
21	Solenoids Valve Unit	1.7	06		
22	Solenoids Power Circuit	2.9	08		
23	Fuel Sensor	1.6	02		

C. Troubleshooting A

Troubleshooting A refer as a procedure in which any fault codes are displayed after diagnosing the Main Controller (MC) using the built-in diagnosing system or the service menu of monitor unit.

D. Troubleshooting B

Troubleshooting B refers as a procedure in which no fault code is displayed on the built-in diagnosing system although the machine's operation is abnormal. The troubleshooting B indicates the relationship between machine trouble symptoms and related parts which may cause such trouble if failed. Start the troubleshooting with more probable causes selected by referring to machine trouble symptoms and related parts failure.

In case any fault code has not been displayed in built in diagnostics system, we preferred to perform inspection of components in accordance with the Troubleshooting B procedures (for diagnosing the fault). When the fault code is displayed in built in diagnostics system, we referred to the troubleshooting A group and diagnose in accordance with that.

Relationship between machine trouble symptoms and related parts

The diagnostics system indicates the relationship between machine trouble symptoms and the potential problem parts/components, which may cause trouble if failed. So, analyses of these components are necessary.

The trouble symptoms in this diagnostics system are described provided that each trouble occurs independently. In case more than one trouble occurs at the same time, we can check all faulty components while diagnosing all suspected components in each trouble symptom.

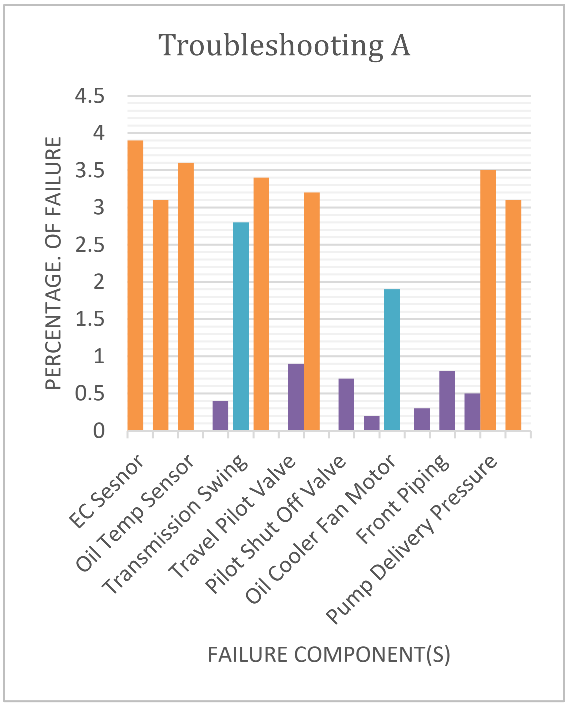


Figure 29-1 Troubleshooting A

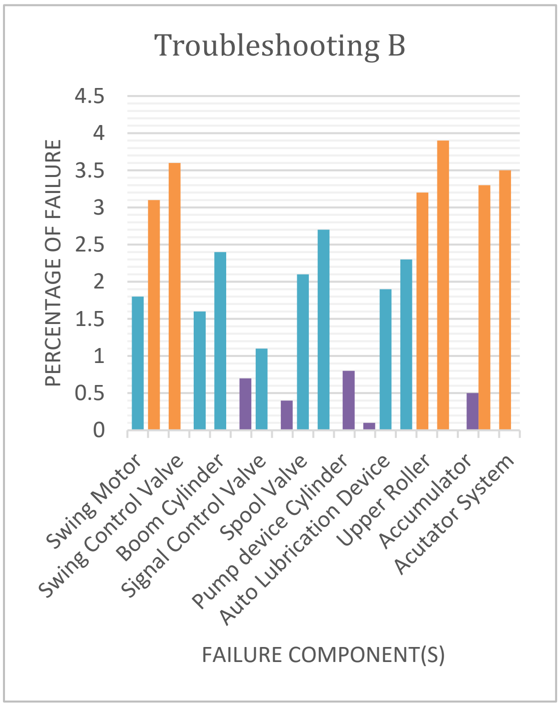


Figure 29-2 Troubleshooting B

E. Troubleshooting C

(Troubleshooting for monitor procedure)

Troubleshooting C refers as a procedure in which no fault code is displayed on the built-in diagnosing system although the machine's operation is abnormal. The troubleshooting C related to monitors, such as gauges or indicators malfunction. This includes malfunction of coolant temperature gauge, fuel gauge, indicator light check system, preheat indicator, engine oil level indicator, coolant level indicator, alternator indicator, engine oil pressure indicator, overheat indicator, air filter restriction indicator, buzzer, LCD, hour meter and hydraulic oil filter indicator.

Self-diagnosing service mode

Self-diagnostics service mode has three operating modes, learning value display, parameter change, and monitor display information setting referred as Troubleshooting A, B and C respectively. Learning value display includes abnormal EC sensors, engine control dial angle, boom angle sensor, pump delivery pressure, pump control pressure, swing pilot pressure and oil temperature etc. Parameter change includes engine speed, pump delivery flow rate, and solenoid valve output pressure, actuators, boom angle, swing speed etc.

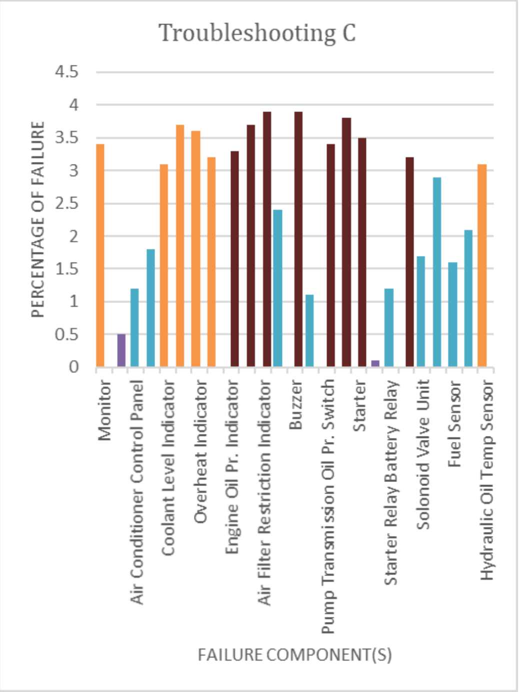


Figure 29-3 Troubleshooting C

Table 29-4 COLOUR VS REMARK OF THE TROUBLESHOOTING GRAPHS

Colour	Remark
Green	Failure Rate High / Down Time High or Medium
Yellow	Failure Rate Low / Down Time High
Brown	Failure Rate High/ Down Time Low
Blue	Failure Rate Low or Medium/ Down Time Low

COMPARISON OF RESULT

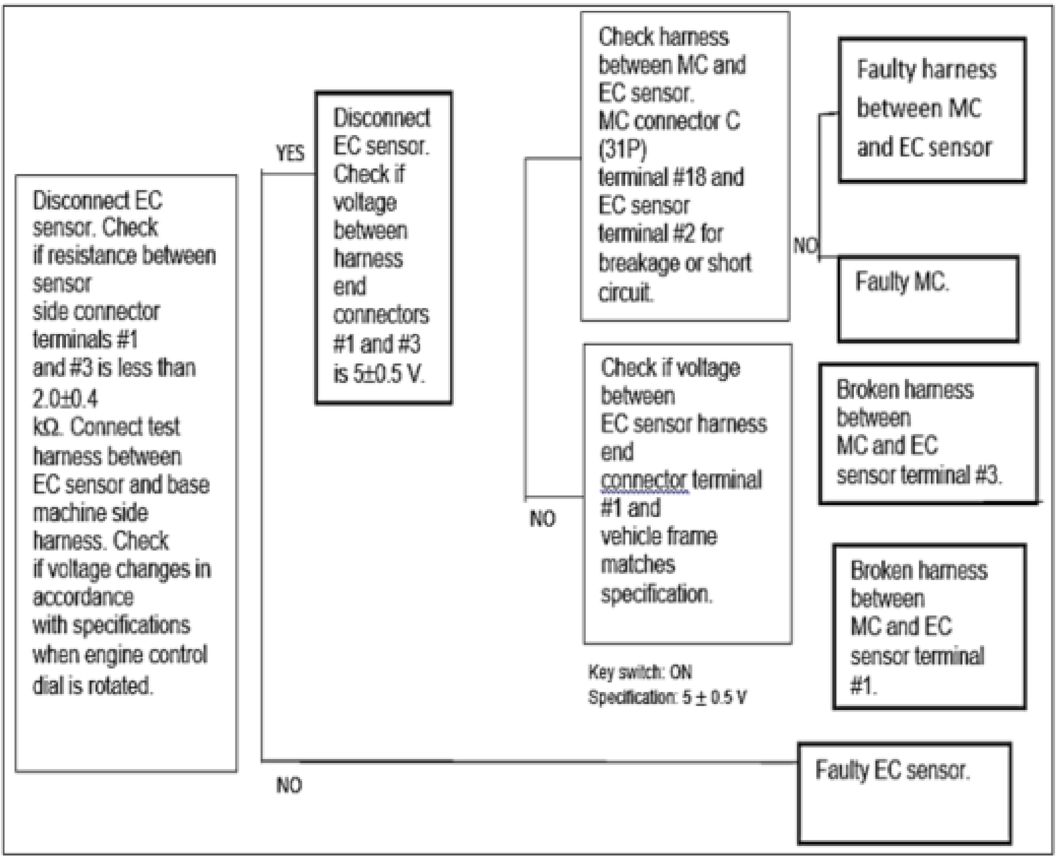
Research is still continuing, as it is the case in any area of knowledge, to understand machine performance and maintenance in greater details. However, such investigations have been found to readdress some specific areas of the whole problem, including performance, maintenance, reliability, utilization, machine-material interaction etc.

EXPERT SYSTEM DESIGN WITH THE HELP OF TROUBLESHOOTING SHEET

While designing the IoT maintenance system, performance of conventional methodologies was verified using mining statistical data. For the development of this System, the standardization of the failure codes was classified. The critical components were identified and codes were given to the individual faults. Coding process was streamlined through JAVA programming language. The JAVA programming language has an advantage over other programming language (LISP and PROLOG) is that: it has extensive data manipulation capability, incremental compilation facility, labelled memory architecture, efficient search and memory management procedure and also to optimize the system environment.

Analyses were done through the failure history analysis, maintenance manuals, and the expert knowledge. The rule base (algorithm) has been constructed in order to develop decision support system to operational maintainability. Based on these algorithm program was written. The goal of the system is to provide expertise to the non-experts in mining industries with a list of possible failure modes and decisions to be adopted.

The excavator's components were categorised as Troubleshooting A, B and C according to their function and fault classification. The rule/knowledge based (algorithm) system (fault diagnostics system) for various components of excavator has been constructed and explained in next section (Algorithm for Troubleshooting). Based on these algorithm program was written using JAVA programming language. ***The Program is appended in Annexure I.*** Example of Troubleshooting / Troubleshooting A Fault: Abnormal EC Sensor is illustrated by Figure 29-4.



EC Sensor	Specification:
Slow Idle	2.5V to 2.7V
High Idle (HP mode Switch: OFF)	3.3V to 3.7V
High Idle (HP mode Switch: ON)	Voltage at Fast Idle (HP Mode Switch: OFF) plus 0.2 V or more

Figure 29-4 Abnormal EC Sensor

Annexure I (PROGRAM FOR ABNORMAL EC SENSOR)

```
import java.util.*;
public class Troubleshooting_A
{
public static Scanner sc=null;
              public static void A6()
              {
              System.out.println("resistance between sensor side connector terminals #1 and #3 is less than 2.0±0.4kO.Enter y for yes and n for no");
              String a1=sc.next();
System.out.println("voltage changes in accordance with specifications when engine control dial is rotated.Enter y for yes and n for no");
              String a2=sc.next();

              if(a1.equalsIgnoreCase("y") && a2.equalsIgnoreCase("y") )
                                                          {
              System.out.println("voltage between harness end connectors #1 and #3 is 5±0.5 V.Enter y for yes and n for no");
String a3=sc.next();

        if(a3.equalsIgnoreCase("y"))
        {
                System.out.println("Check harness between MC connector C (31P) terminal #18 and EC sensor terminal #2 for breakage or short circuit.Enter y for yes and n for no");
                        String a4=sc.next();

                        if(a4.equalsIgnoreCase("y"))
                        {
                                        System.out.println("Faulty harness between MC and EC sensor");
                        }
                        else
                        {
                                System.out.println("Faulty MC.");
                        }
        }
        else
        {
                System.out.println("Check if voltage between EC sensor harness end connector terminal #1 and vehicle frame matches specification.Enter y for yes and n for no");
                        String a5=sc.next();

                        if(a5.equalsIgnoreCase("y"))
                        {
```

```
                                        System.out.println("Broken harness between MC and EC
sensor terminal #3.");
                        }
                        else
                        {
                                System.out.println("Broken harness between MC and EC sensor
terminal #1.");

                        }


        }


                                                      }
                                                      else
                                                      {

             System.out.println("Faulty EC sensor.");
```

CONCLUSION

The existing Indian scenario in terms of machine maintenance reveals the predominance of breakdown maintenance culture in the coal industries in particular and industries involving heavy earth moving machinery in general.

Considering the high capital cost and limited life of the main excavators, breakdown maintenance is not a right approach wherein a machine is attended for maintenance only after a component or a sub system breaks.

So, it is imperative to have some well researched diagnostic maintenance methodologies with efficient algorithmic solutions which will maintain the ill structured symptoms of failures through constant monitoring of the machines health and performance to keep it at the desired or standardized availability/ reliability level.

While designing the expert maintenance system, performance of these methodologies was verified using mining statistical data. For the development of this ES, the standardization of the failure codes were classified. The critical components were identified and codes were given to the individual faults. Analyses were done through of the failure history analysis, maintenance manuals, and the expert knowledge. The rule base (algorithm) has been constructed in order to develop decision support system to operational maintainability. Based on these algorithm program was written using JAVA programming language. The goal of the system is to provide expertise to the non-experts in mining industries with a list of possible failure modes and decisions to be adopted.

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