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FAILURE ANALYSIS AND PERFORMANCE IMPROVEMENT USING SURFACE MINER ON FIELD BREAKDOWN DATA: A CASE STUDY

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ABSTRACT :

Over the past few decades, open cast mining operations have steadily increased their production rate by using large mining equipment like a surface miner, bucket wheel excavator, etc. Among them, the surface miner is one of the most popular equipment in coal mining industries, which is used for cutting, crushing and carrying the coal, limestone and other minerals in a single operation without any need for drilling and blasting. Availability of machine depends upon factors like maintainability of a machine, reliability of components, how effectively maintenance procedure is implemented, types of machine, nature of work performed by a machine, environment condition in which machine performing, operator's capabilities or experience, etc. The analysis is concentrated towards the study of the operational systems of surface miner L&T KSM 303. To know about the performance of machine as well as to improve the performance of machine,breakdown and operational data collection and its analysis is one of most important task which help in assessment of availability,critical components,Mean Time Between Failure(MTBF), Mean Time To Repair (MTTR), etc. of the machine. Generally, To reduce the unplanned breakdown of machine, there is need to increase the reliability of each component by implementing the different research methodology like Failure Mode, Effects and Criticality Analysis (FMECA) and Fault Tree Analysis (FTA)

KEYWORDS: Failure Analysis, FMECA, FTA, surface miner, Utilization.

1. INTRODUCTION

Over past few decades, open cast mining operations have steadily increased their production rate by using large mining equipment like surface miner, bucket wheel excavator, etc. Among them, the surface miner is one of the most popular equipment in coal mining industries, which is used for cutting, crushing and carrying the coal, limestone and other minerals in a single operation without any need for drilling and blasting. The major assemblies of this machine are crawler system, cutter drum assembly, hydraulic system, engine assembly and instrumentation and control.

Generally, in mining operation, working environment is worst which degrades the components quickly and leads to frequently breakdown of machine i.e. affecting availability, operating cost and maintenance cost. In this machine, Preventive Maintenance (PM) strategy is being carried out to prevent from unplanned breakdowns. In spite of this, machine breakdown is happening frequently, and these breakdowns occur due to failure of crawler system, engine starting problem, and electrical system problem. For this, operational data collection and its analysis are one of most important task which helps in assessment of availability of machine, critical components, expected life of the different components, total number of failures, total breakdown hours, Mean Time To Failure(MTTF),Mean Time To Repair(MTTR), Mean Time Between Failure (MTBF), etc.

The failure analysis will help in determining the different critical system of the surface miner and their critical failure modes of critical system and root causes of these critical modes. The failure analysis can be achieved by data analysis, failure mode, effects and critical analysis (FMECA), and fault tree analysis (FTA). Based on failure analysis, the recommendations-based solution will be identified to enhance the output of surface miner.

2. LITERATURE REVIEW AND PROBLEM FORMULATION

2.1 Failure Analysis

Srivastava and Kumar [1] described Condition Based Maintenance Architecture for optimal maintainability of Mining Excavators and used the FMCEA (Failure mode, effects and criticality analysis) and FMEA (Failure mode and effects analysis) techniques to find the critical components of machine and their failure modes. Kumar and Srivastava [2] described a new method of failure analysis that is FDPM (Fault Detection and Preventive Maintenance) technique for predictive maintenance of mining excavators. The FDPM helps to identify, detect and locate the faults by using historical machine data, statistical fault analysis method, etc. which lead to improve the productivity of machine as well as reduce the unit cost production. This technique involved collection of details of all the components from manufactures as well as operational data from site. This helps to improve the mean time between failures which will lead to increase the productivity of system. Chetan and Chattopadhaya[4] carried out in reliability analysis of bulldozer.

Barabady and Kumar [5] studied reliability of mining equipment using the distribution theory. Chandra et al. [6] carried out RAM (Reliability, availability and maintainability) analysis on dumpers using non-parametric technique like Kaplan-Meir Estimation to evaluate the reliability and performance of dumper. This method is not accurate and cannot predict the reliability as well failure rate of machine. It is rarely used for mining equipment. Islam [7] described a procedure to evaluate and predict system reliability. In this procedure, breakdown data need to be analyzed and check if this data follows any types of distributions like normal, exponential, Weibull, logarithm, etc. If it follows a particular distribution, one can easily predict when failure of the system will occur. Mariam [8] described about reliability centered maintenance (RCM) of rotating equipment through predictive maintenance. . Rai P., Yadav U. and Kumar A[9] : The study has revealed the following importance of dragline on the performance of mining industry 1. The preparation of balancing diagram for planning of dragline operations is the first and the most important step, its actual implementation is equally important.2. The importance of appraisal of dragline productivity parameters, such as, cycle time, swing angle, seating position, availability, utilization, etc., in the field scale. U Kumar [10] explains the details of an availability study for a fleet of diesel engine operated load-haul-dump (LHD) machines used in a Swedish mine. F Anvari, R Edwards, A Starr [11] illustrates a new method, overall equipment effectiveness market-based (OEE-MB) for the precise calculation of equipment effectiveness. . Jeong K. and Phillips D.T. discussed [12] a new loss classification scheme for computing the overall equipment effectiveness (OEE) for capital-intensive industry. Jonsson P., and Lesshammar M [13], paper identifies six requirements: four critical dimensions (what to measure) and two characteristics (how to measure) of an overall manufacturing performance measurement system.

2.2 Problem Formulation

'Failure analysis of Surface Miner', A main problem occurring in L&T the surface miner is unplanned breakdown of machine and low production output. Due to this, the mean time between failure (MTBF) decreases and mean time to

2.3 Objective of Research

A main objective of the project is to reduce the unplanned breakdown and enhance the production output of surface miner.

3. DESCRIPTION OF SURFACE MINER

Under this section we are going to understand the working & construction of different parts of Surface Miner KSM -303.

3.1 Surface Miner

The surface miner considered for this project is 'L&T KSM 303'which is shown in given Fig.1. Its line diagram shown in Fig.2. Major assemblies and their description is given in next section.

Fig.1: Photograph of 'L&T Surface MinerKSM 303'

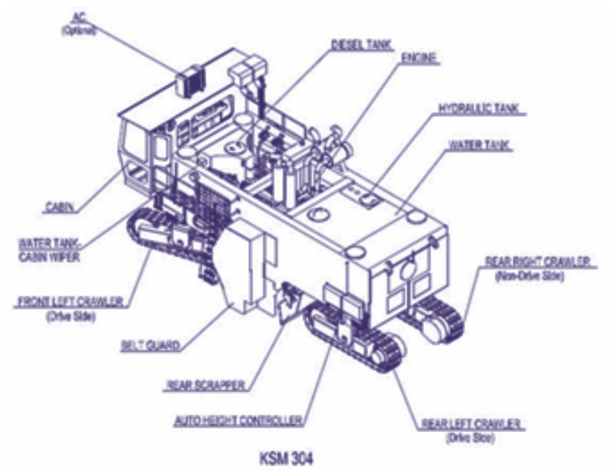

Fig. 2 Line diagram of L&T surface miner[20]

Table 1: Technical Specifications

Sl.no	Components description	Specification
1.	**Engine**	
	Engine rating	800 hp @ 1800 rpm
	Type	Turbo charged after water cooled,60-v cylinder
	No. of cylinders	12
2.	**Speed/grade ability**	
	Operating speed	0-30 m/min
	Travel speed	0-4 km/hr.
	Theoretical grade ability	50%
	Max. transverse gradient	12%
3.	**Cutting drum**	
	Drive	Mechanical
	Cutting drum depth	0-300mm
	Cutting drum width	3000mm
	Cutting drum dia. With tools	1150

4.	**Dimensions**	
	Width	4600
	Length	8500
	Height (drum tip to cabin top)	4500
5.	Weights	
	Operating weight	54 ton
	Operating weight, full tanks	57 ton
6.	**Crawler tracks**	
	No. of track	4
	Track dimensions(L*W*H*)	2650*400*818
7.	**Tank capacities**	
	Fuel tank	1600 liter
	Hydraulic oil tank	650 liters
	Water tank	4800 liters
8.	**Electrical system**	
	control	24-volt dc
	lighting	24-volt dc

3.2 Major Assemblies And Their Description

The major assemblies of the surface minerare shown in Fig.3. which are crawler system ,engine assembly , cutter drum assembly , hydraulic system , fuel line assembly , chassis/structure , and electrical system.These assemblies consist of different components which are shown below in Fig. 4.

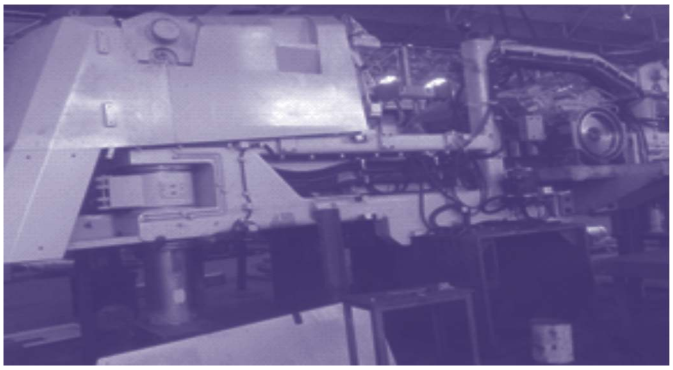

Fig.3: Photograph of major assemblies of Surface Miner

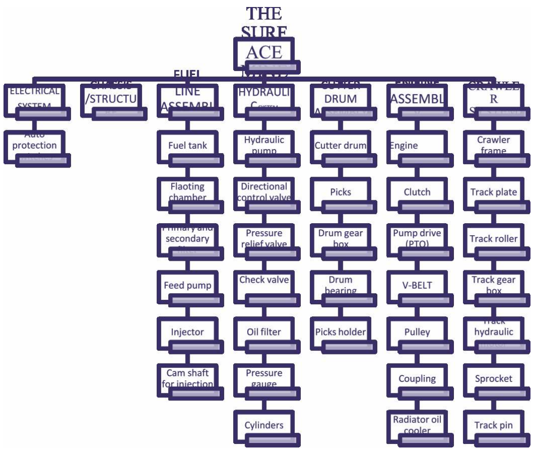

Fig. 4 Components of the Surface Miner

1. Crawler system: It is bottom most part of the machine, which is used to carry whole load /weight of machine as well as its main function, it moves the machine in forward and backward direction.

2. Cutter drum assembly: It is shown in Fig. 5. The main function of this assembly is to cut, crush and transport the coal, lime stone and other minerals from excavated area to dumper. It is driven by engine through v-belt arrangement, which is connected between engine pulley and drum pulley

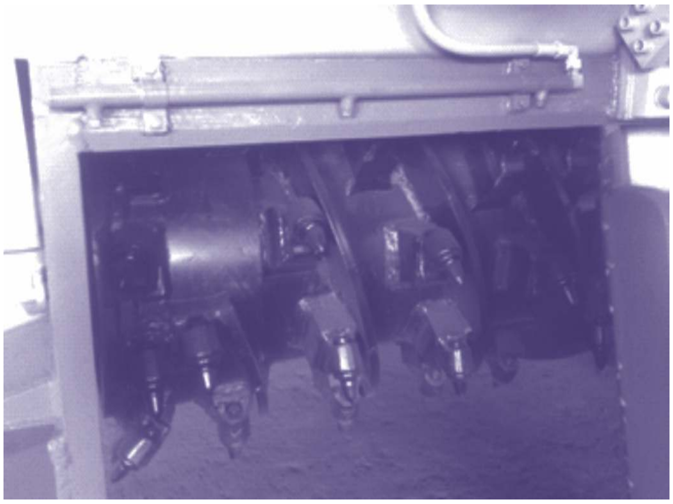

Fig. 5 Cutter drums assembly

3. Engine and drive assembly: It is shown in Fig. 6. The engine used for driving the surface miner is v-type IC diesel engine which consists of twelve cylinders with turbo charged facility as well as water cooling system. It provides power to every power-driven component directly or indirectly. A clutch is fitted on the other side of pump drive (PTO) for driving the milling drum via v-belt.

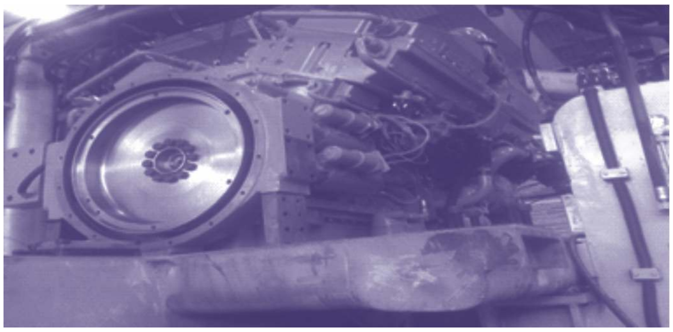

Fig. 6: Engine and drive assembly

4. Hydraulic system: Hydraulic system is used in the surface miner for driving, lifting & lowering, steering, braking of the machine and other auxiliary drive (AC, water spray etc.).

5. Radiator Oil Cooler (ROC): During combustion of fuel inside the engine, a lot of heat is generated, which increases temperature of the engine. So there is need of cooling system to cool the engine to reduce above effect. Generally, oil cooling system is used more frequently compared to air cooling system. In this system, pressurized oil coming from pump is circulated around the engine, which absorbs heat from the engine and it gets cooled by water and this hot water passes through the radiator Oil cooler is attached to radiator for cooling the hydraulic and lubrication oils.

6. Water spray cooling system for dust suppression: The main function of this water spray system is to remove the heat from drum cutter as well as to suppress the dust particles generated during the cutting action of drum

7. Fuel line assembly: A main function of fuel line assembly is to provide the fuel at right quantity at right time to engine. The fuel is passed through the primary and secondary filters to remove all the dirt and impurities contained in the fuel. After passing through filter, the fuel after this pass through feed pump. The time interval between two consecutive injections is controlled by cam shaft which is attached to crank shaft of the engine.

8. Chassis frame /main frame: The main frame is made up of high tensile plate for higher stiffness and high torsion rigidity. The machining is done after completion of fabrication and heat treatment is done to reduce the residual stress as well as for accurate alignments to avoid the distortion later

9. Instrumentation and control system: It is purely electronic system, which controls the whole dynamics of machine if it is going beyond the standard limit. One of the important devices used in control system is micro-controller that is used for controlling vibration with all safety interlocks for smooth operation of the machine. There is a dual control in cabin –LH panel and RH panels provided, with alphanumeric display for current status and fault condition.

The other major control systems available in the surface miner are as

- Engine overload protection system
- Alarm for high oil temperature and high pressure
- Engine protection interlocks
- Safety protection for maintenance work
- Emergency stop buttons for all ground movement
- Auto fire suppression system
- Air compressor for greasing.

4. PROJECT METHODOLOGY, OVERVIEW OF FMECA AND FTA AND DATA COLLECTION

4.1 Overview of Project Methodology

This section provides an overview of FMECA and FTA, and data collection. A main objective of this project was to carry out failure analysis of 'L&T Surface Miner KSM 303', which means to it improve mean time between failures (MTBF) and reduce the mean time to repair (MTTR) as well as to increase utilization hours.

The overall methodology is limited to failure analysis and is performed for the surface miner. Data analysis will help in finding number of failures occurred for each system, Mean Time To Failure (MTTF), Mean Time To Repair (MTTR) of surface miner, and total breakdown hours of surface miner. FMECA will help in finding critical modes of failure by evaluating Risk Priority Number (RPN). FTA will help in finding root causes of each top event/critical failure mode and also probability of unavailability of the surface miner attributed to these failure events. After the analysis, recommendation-based solutions are to be provided, which will enhance the performance of machine as well as reduced the unplanned breakdowns of machine

4.2 Overview of FMECA And FTA

FMECA is a well-known procedure in reliability and safety that will be used in failure analysis. A failure mode means how a failure is observed, reasons for failure, its effect and consequences on the other components of system, person and environment are to be examined. Criticality of any failure mode is evaluated on basis severity level on system, probability of occurrence, and detectability of failure modes. RPN (Risk Priority Number) is function of above three factors and its value is product of these three factors. RPN has direct relation with criticality of failure mode. It is defined as

$$\text{RPN (Risk Priority Number)} = \text{Severity level} * \text{Probability of occurance of failure mode} * \text{detection level}$$

The Tables 2-4 are given below for finding the criticality of failure Mode

Table.2. Severity level

Rating	Description	Criteria
1	Very low or none	Minor nuisance
2	Low or minor	Product operable at reduced Performance
3	Moderate or significant	Gradual performance degradation
4	High	Loss of function
5	Very high or catastrophic	Safety-related catastrophic failures.

Table.3. Probability chart

Rating	Class	Description
5	Frequently (5)	Likely to occur frequently (>0.01)
4	Reasonably probability (4)	Will occur several time in life of item (0.01 - 0.006)
3	Occasionally (3)	Likely to occur sometime (0.006-0.001)
2	Remote (2)	Unlikely, but possible to occur (0.001 -0.0001)
1	Extremely impossible (1)	So unlikely, but not possible (<0.0001)

Table.4. Detection chart

Rating	Detection criteria
5	Almost uncertainty
4	Remote
3	Low
2	Moderately high
1	Almost certain

FTA is another well-known method or approach to find root causes of a failure i.e. a top event. It helps in analysis to identify root causes for system failure as well as combination of events that are responsible for failure of the system. It is diagrammatic procedure uses the logic gate like AND, OR, etc. Minimal cut sets are collection of basic event on which occurrence of top event depends and it is evaluated by Boolean algebra.

5. FAILURE ANALYSIS

In this segment, breakdown data analysis has been carried unit 15 of 'L&T Surface Miner KSM 303'to find out the critical components of machine, MTTF, MTTR etc. FMECA and FTA will be carried out on critical systems of machine. In FMECA, Risk Priority Number (RPN) of different failure mode of different critical systems will be evaluated. From that analysis, the graphs are plotted for different failure modes for critical system. Further, FTA is carried out to find the root causes of the failure and to find out unavailability probability of the surface miner.

5.1 Breakdown Data Analysis

In this breakdown data analysis, raw data has been segregated according to the system wise. Number of failures and breakdown hours and percentage of failure of different system are evaluated. Apart from this, mean time to failure (MTTF), and mean time to repair (MTTR) of the surface miner are evaluated. The breakdown analysis is given in Table 5-6. In Table 5.1, the failure percentage of different systems of 'L&T KSM 303 (UNIT 15)' has been shown. From the table, it is clear that most critical systems of the surface miner is crawler system with percentage of failure approx. 25%, followed by engine assembly with percentage of failure approx. 20.3% , followed by electrical system with percentage of failure 12.1% and so on.

Table: 5 Parameter Descriptions

SL.NO	parameter descriptions	Value (unit)
1	Number of times machine got failure	410
2	Total breakdown hours	3974.5
3	Engine hours meter reading as on 31.05.2016(EHMR)	17137
4	Mean time between failure (in terms of EHMR)	41.79
5	Mean time to repair (in terms of hours)	9.6

Table.6.: Breakdown data analysis for different systems of L&T KSM 303 (Unit 15)

Sl.no	System description	No. of failure	Failure occurrence (%)	Breakdown hrs.	Breakdown hour's (%)
1	Crawler system	103	25	1065	34.4
2	Engine	85	20.30	847.5	27.38
3	Milling drum system	22	5	297	9.5
4	Electrical system	50	12.00	292.5	9.4
5	Hydraulic system	48	11.70	227	7.33
6	Steering system	13	3.70	172	5.5
7	Engine cooling system	5	1.20	118	3.8
8	Clutch	6	1.40	76	2.4

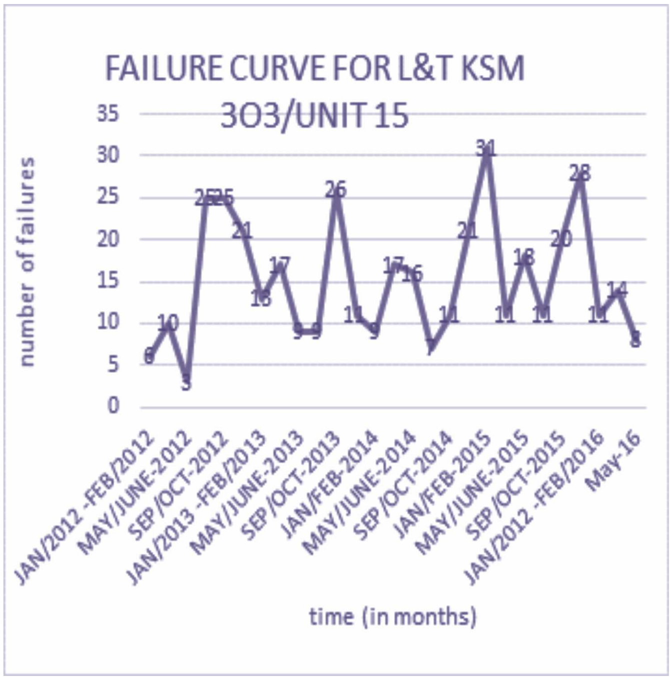

Fig. 7 Failure curve of 'L&T Surface Miner UNIT 15'

Failure curve of surface miner

The graph has been plotted between numbers of failures that occurred in machine with respect to time (month wise) which are shown in Figs. 7. The following are the observations from two graphs. The number of the failures occurred is highly fluctuating in nature and it generally lies between 5 to 30.The maximum number of failures in 'L&T KSM 303/UNIT 15' is 31 and 28 during the month of January 2015 and December 2015 respectively.

5.2 Application of FMECA

Brief detail of FMECA is given in section 4.2. In this section, the focus has been given on what are different failure modes of critical systems. Criticality of each failure mode is obtained by allocating the risk priority number. Following failure mode descriptions has been given below for different systems.

5.2.1 Failure modes of crawler system

From Fig. 8, it is observed that, the maximum probability of occurrence of failure mode is due to track chain out and this failure mode contributes around 0.623% of total probability of occurrence of failure. The second most critical failure mode in this system is track pin and plate failure (0.6%), followed by track gear box failure (0.355%). FMECA procedure has been applied to crawler system and is shown in Table.7. From this table, track chain out and track pin failure modes are most critical failure mode of crawler system with RPN value of 80. It is followed by track gear box failure mode with RPN value of 60.

Table.7. FMECA chart for crawler

S. No	Components	Components function	Failure mode	Effect of failure on system	Severity rating	Causes of failure	Failure occurrence	occurrence	Probability rating	Immediate control action	Detection Risk priority	rating number (RPN)
1	Crawler System	Move the machine backward and forward	track chain out (4S)	high severity	4	Due to lack of proper tensioning of Track due to over steering of machine elongation of track link due to thermal expansion	0.006	reasonable probability	4	system shutdown	5	80
2			track gear box failure	high severity	4	wear and tear of hydraulic motor due to aging quick damage due to entering of dust particles with oil due failure of gear box bearing supply of high-pressure oil to gear box	000355	occasionally	3	system shutdown	5	60
3			track pin, plate broken	high severity	4	due to over tensioning of track due to no proper levelling of ground due to over steering of track due to use of low-quality pin material	0.006	Reasonable probability	4	system shutdown	5	80
4			track idler failure	high severity	3	due to no proper leveling of ground Jack of proper lubrication due to use of low-quality pin material	0.000732	Remote	2	system shutdown	5	30
			track tensioner failure	high severity	4	due to over tensioning of track due to damage of spring	negligible	rare	1	still system can run	4	16

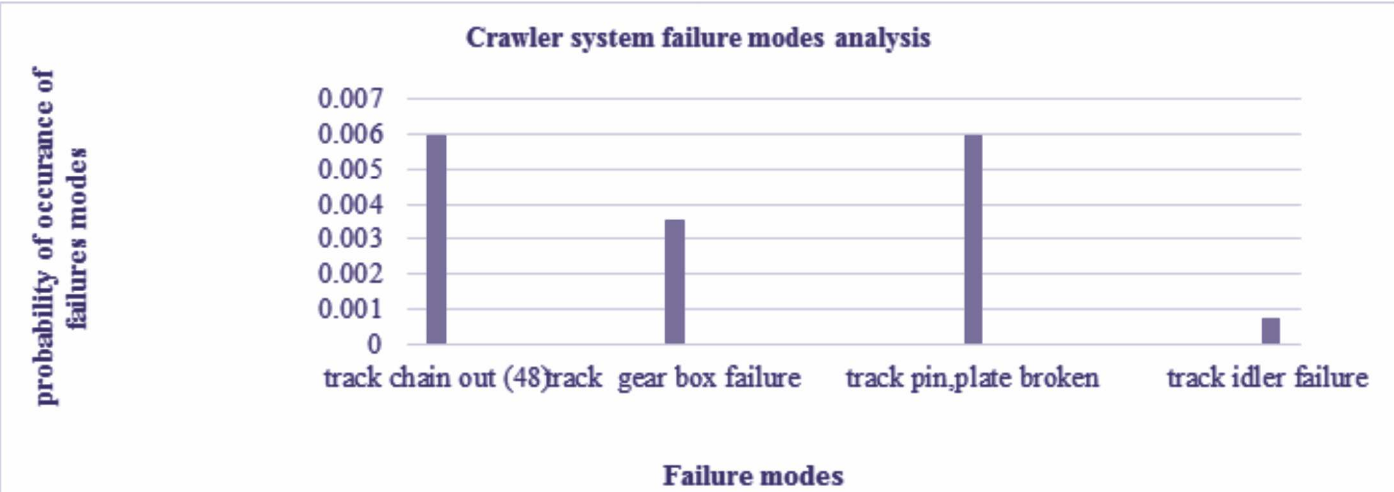

Fig. 8. Crawler system failure modes analysis

5.2.2 Failure modes of engine

From Fig.9, it is observed that, the maximum probability of occurrence of failure mode is due to starting problem and this failure mode contributes around 1.2% of total probability of occurrence of failure .The second most critical failure mode in this system is engine clutch failure (0.332%),followed by engine fuel line (0.04%). FMECA procedure has been applied to engine and is shown in Table.8. From this table, starting problem is most critical failure mode of engine with RPN value of 100. It is followed by engine fuel line and engine clutch failure mode with RPN value of 60.

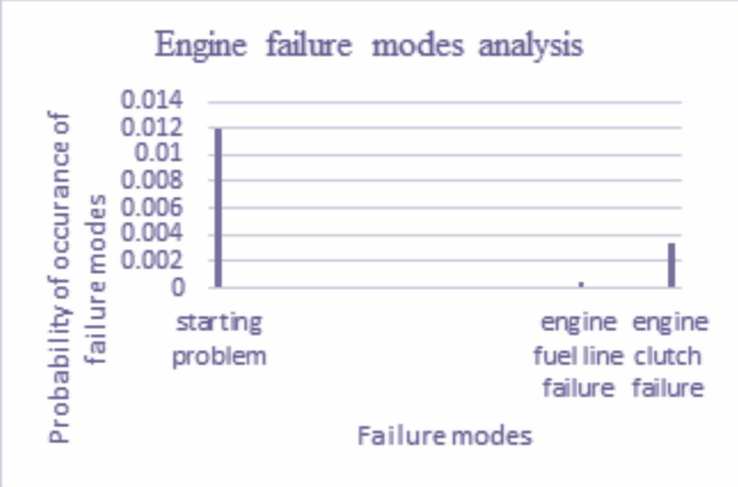

Fig. 9. Engine system failure modes analysis

Table 8. FMECA chart for engine assembly

S.No	Components	Components function	Failure mode	Effect of failure on system	Severity Rating	Causes of failure	Failure occurrence	occurrence	Probability rating	Immediate control action	Detection Rating	Risk Priority Number (RPN)
1	Engine	To supply power to machine	starting problem	high severity	4	electrical problem: contact switch problem starting motor problem electrical circuit problem starting battery not charged short circuit problem electronic fuel controller not functioning mechanical problem: starter gear box problem crank shaft bearing problem piston jammed air lock problem fuel circuit problem: fuel line jammed or damaged no fuel in tank oil filter chocked fuel injector problem	0.012	frequently	5	System will not run	5	100
2			engine fuel line failure	high severity	4	fuel line linkage fuel pump not working fuel line jammed fuel not in tank	0.000421	occasionally	3	System will not run	5	60
3			engine clutch failure	high severity	4	clutch pulley bolt damaged clutch hub thread damaged mechanical breakage due to sudden jerk or load low strength of clutch material used	0.00332	occasionally	3	System shutdown	5	60

5.2.3 Failure modes of Milling drum system

From Fig. 10, it is observed that, the maximum probability of occurrence of failure mode is due to milling drum gear box failure and this failure mode contributes around 0.7% of total probability of occurrence of failure. The second most critical failure mode in this system is picks failure (0.39%), followed by v-belt assembly (0.025%). From the table. 9 mentioned below, it is clear that, milling drum gear box failure mode are most critical failure mode of milling drum system with RPN value of 48. It is followed by v-belt assembly failure mode with RPN value of 36.

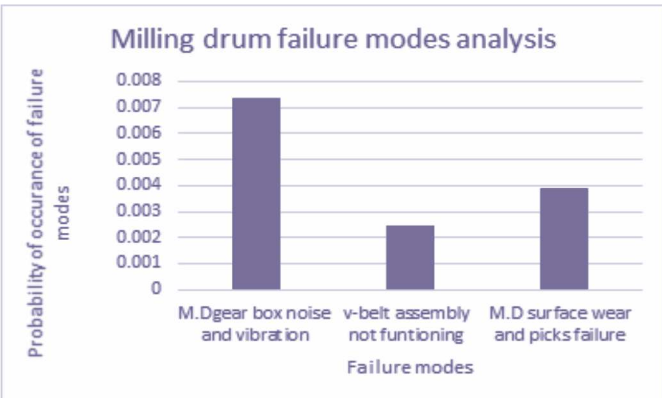

Fig.10. Milling drum system failure modes analysis

Table.9. FMECA chart for milling drum

S. No	Components	Components function	Failure mode	Failure on system	Severity Rating	Causes of failure	Failure Occurrence	Occurrence	Probability Rating	Immediate Control Action	Detection rating	Risk Priority Number(RPN)
	Milling Drum System	To Excavate the Coal from ground	M.D gear box noise & Vibration	High severity	4	Gear teeth got wear & tear gear shaft got cut	0.00737	Reasonable probability	4	System shutdown	3	48
			M.D gear box high temperature	High severity	4	insufficient lubrication circulation leakage of lubricant oil						
			milling drum gear box seal damaged	High severity	4	Due to mechanical wear & tear of oil seal, due to rubbing with dust particle and gear teeth chip due to high temperature of gear box						
			Milling drum bearing failure	High severity	4	insufficient lubrication circulation quickly wear and tear due to dust particles failure due to crack developed on case surface of bearing						
			v-belt assembly not	High severity	4	v-belt pulley bearing got failure V-belt pulley shaft got damaged V-belt getting slip due to lack of sufficient tension V-belt got worn out or damage	0.00247	occasionally	3	System shutdown	3	36
			M.D surface wear & picks failure	Moderate Severity	3	Due to abrasion or wear & tear with ground Mechanical damage due to impact load of surface	0.0039	occasionally	3	Still system can run	2	18

5.2.4 Failure modes of Hydraulic system

From Fig.11 , it is observed that ,the maximum probability of occurrence of failure mode is due to hydraulic lifting cylinder failure and this failure mode contributes around 0.308% of total probability of occurrence of failure .The second most critical failure mode in this system is oil pump failure (0.276%),followed by hydraulic hose leakage (0.25%). From below mentioned table.9, it is clear that hydraulic lifting cylinder failure mode are most critical failure mode of hydraulic system with RPN value of 60. It is followed by oil pump and hydraulic hose burst failure mode with RPN value of 48 and 40 respectively.

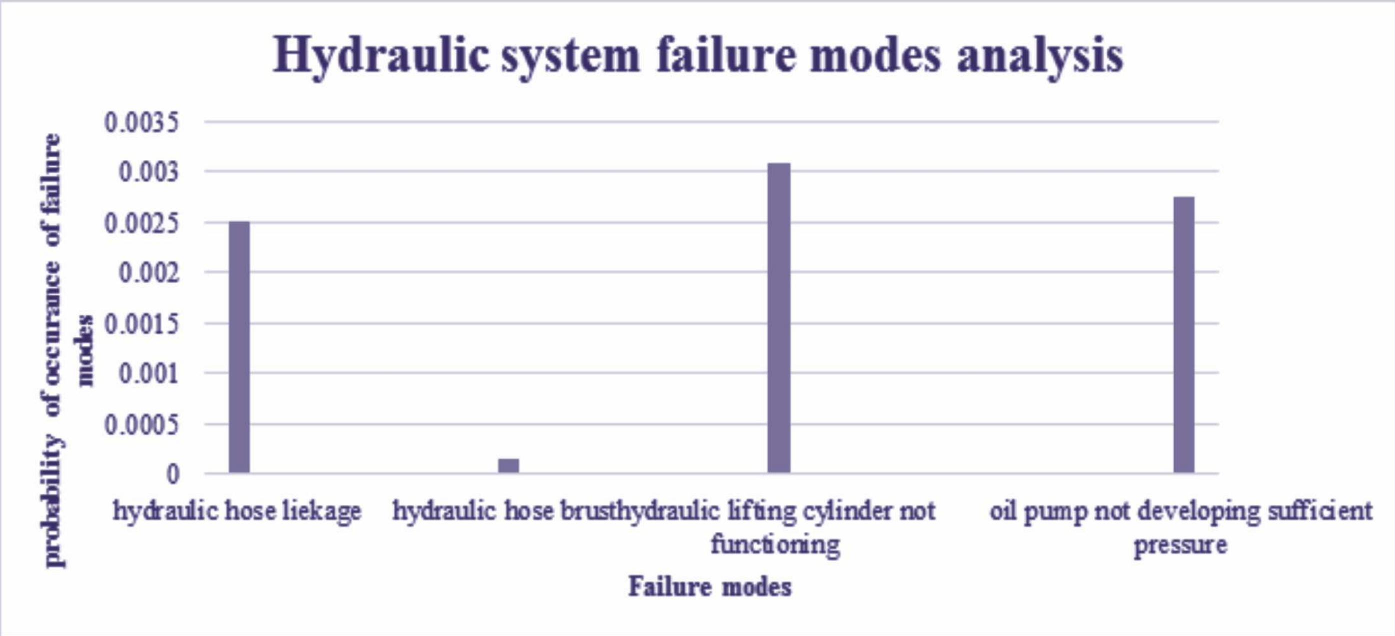

Fig.11. Hydraulic System Failure Modes

Table.10. FMECA chart for Hydraulic System

S.No	Components	Components function	Failure mode	Failure on system	Severity Rating	Causes of failure	Failure Occurrence	Occurrence	Probability Rating	Immediate Control Action	Detection rating	Risk Priority Number (RPN)
	Hydraulic System	To supply the high-pressure oil/water	Hydraulic hose liekage	Low severity	2	Wear & tear due to rubbing with ground Low quality of hose used lack of improper routing of hose line	0.0025	Occasionally	3	Still system can run	4	24
			Hydraulic hose burst	High severity	4	High pressure fluid supplied i.e beyond the limit of hose capacity. Due more number of bends in hose line Low quality of hose line used	0.00015	remote	2	System shutdown	5	40
			Hydraulic lifting cylinder not functioning	High severity	4	Electrical circuit problem hose line liekage pump fault Solenoid valve problem not sufficient oil available in oil tank	0.00308	Occasionally	3	System shutdown	5	60
			Oil pump not developing sufficient pressure	High severity	4	Due to insufficient amount of oil in oil tank Hose liekage in suction & delivery line /damaged/Jammed Oil Pump seal got damage Due to air trapped inside pump during suction	0.00276	Occasionally	3	System shutdown	4	48

5.2.5 Failure modes of Steering system

Failure mode in this system is steering tie rod failure (0.001%). FMECA procedure has been applied to steering system and is shown in Table 11. From this table, it is clear that steering tie rod crack failure mode are most critical, and this failure mode contributes around 0.37% of total probability of occurrence of failure. The second most critical failure mode of steering system with RPN value of 40. It is followed by steering block crack failure mode with RPN value of 36.

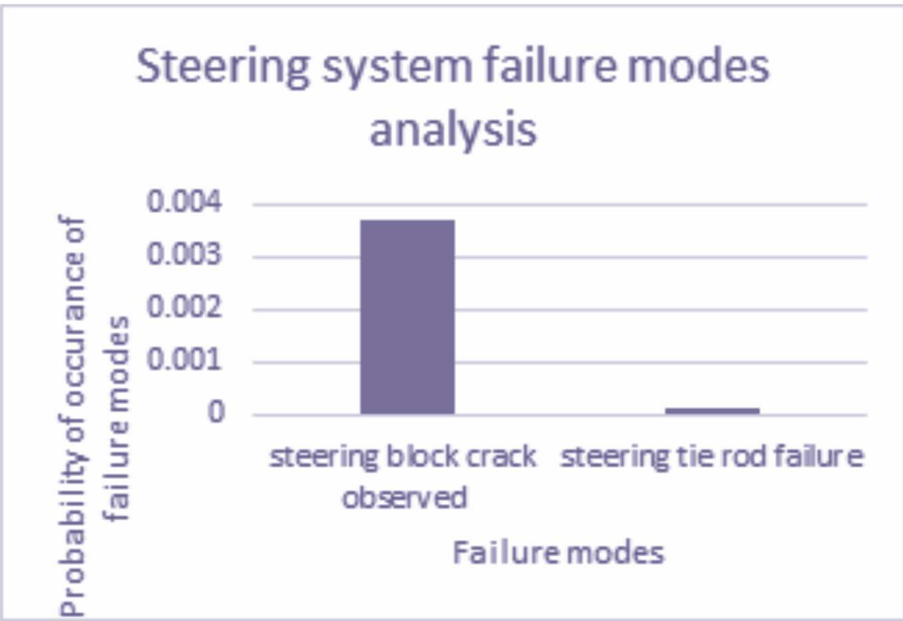

Fig.12. Steering System Failure Modes

Table.11. FMECA chart for steering system

S.No	Components	Components function	Failure mode	Failure on system	Severity Rating	Causes of failure	Failure Occurrence	Occurrence	Probability Rating	Immediate Control Action	Detection rating	Risk Priority Number(RPN)
5	STEERING SYSTEM	Helps in turning of Machine	Steering block crack observed	high severity	4	Due to high rate steering process Steering is done when ground is not properly leveled Due to welding defects at joints Due to very high pressure of oil supplied to cylinder	0.0037	Occasionally	3	System shutdown	3	36
			Steering tie rod failure	high severity	4	Due to very high rate steering process Steering is done when ground is not properly leveled Due to very high pressure of oil supplied to cylinder Low quality material used	0.000104	Remote	2	System shutdown		

5.2.6 Failure modes of Electrical system

From Fig.13, it is observed that the maximum probability of occurrence of failure mode is due to emergency sensor failure and this failure mode contributes around 0.39% of total probability of occurrence of failure .The second most critical failure mode in this system is contact switch failure (0.35%), followed by alternator failure (0.19%). FMECA procedure has been applied to electrical system and is shown in Table 12. From this table, it is clear that emergency sensor not functioning failure mode are most critical failure mode of electrical system with RPN value of 60. It is followed by electrical switch and wiring problem and alternator problem failure mode with RPN value of 48.

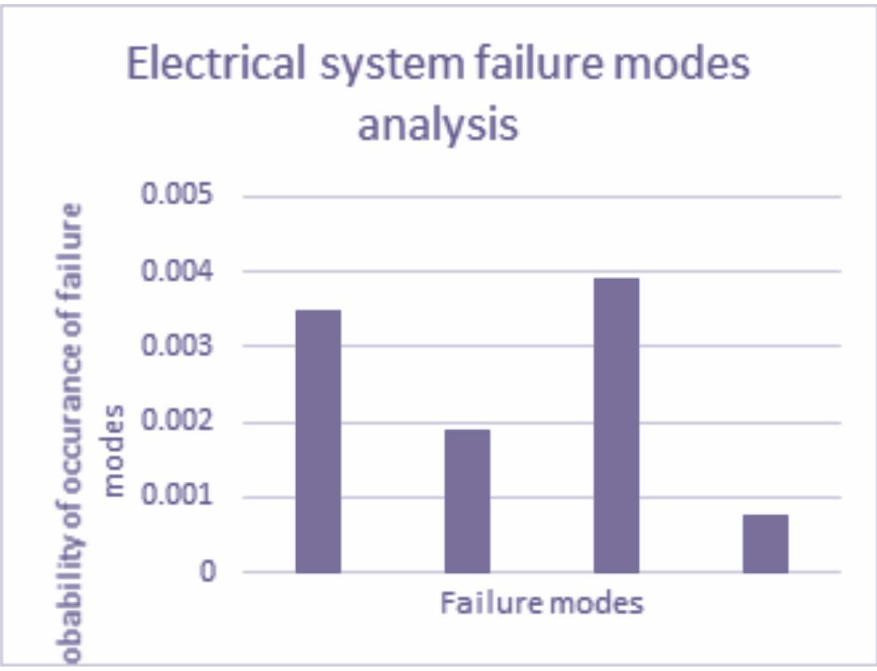

Fig.13. Electrical system failure modes analysis

Table.12. FMECA chart for electrical system

S.No	Components	Components function	Failure mode	Failure on system	Severity Rating	Causes of failure	Failure Occurrence	Occurrence	Probability Rating	Immediate Control Action	Detection rating	Risk Priority Number (RPN)
6	Electrical System	Supply Power to different components	Electrical contact switch, wiring problem	High severity	4	Wear & tear of contact switches Dust deposition occurred over switches Due to wire damaged PLC problem	0.0035	Occasionally	3	Still system can run	4	48
			Alternator failure observed	High severity	4	Alternator relay problem Alternator belt damaged Wire Damaged Joy stick contact switch problem	0.0019	Occasionally	3	Still system can run	4	48
			Emergency sensor fault observed			Auto fire feedback sensor problem Fire extinguisher feedback sensor problem Wire damaged for sensors Relay problem	0.0039	Occasionally	3	System Shutdown	5	60
			Battery Failure	Moderate	3	Charging capability reduced with time Battery pole damaged overcharging	0.000764	Occasionally	3	Still system can run	5	45

5.3 Application of Fault Tree Analysis (Fta)

Brief detail of FTA is given in section 4.2. The main purpose of using FTA tool in failure analysis is to know about the root causes of failure events, minimal cuts set of top events, and probability of unavailability of machine. In Fig. 14, fault tree diagram of the surface miner has been prepared for its top event breakdown of the surface miner using FTA software and all basic events (root causes) are shown. All these basic events of different systems are listed in table 13. In this, it is shown that G1 is top event and G2, G3, G4, G5, G6 and G7 are intermediate event of this FTA. Further expansion of these intermediate events, basic events are identified.

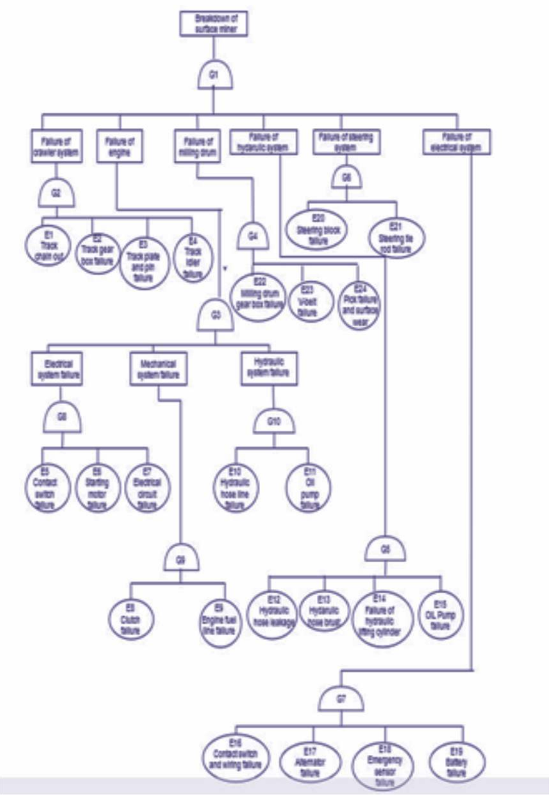

Fig. 14. Fault tree diagram of surface miner

5.4 Minimal Cut Sets

In Table 13, the minimal cut sets of different systems are obtained.

Table.13. Minimal cut sets

Sl. No	System	Minimal cut sets
1.	Crawler system (G2)	E1- track chain out. E2- track gear box failure. E3- track pin, plate failure. E4- track idler failure.
2.	Engine (G3)	E5- contact switch failure. E6- starting motor failure. E7- electrical circuit failure. E8-clucth failure. E9- engine fuel line system failure. E10- cooling system failure.
3.	Milling drum system (G4)	E21-milling drum gear box failure. E22- V-belt assembly failure. E23- picks failure.
4.	Hydraulic system(G5)	E11-hydraulic hose leakage E12- hydraulic hose burst. E13- hydraulic lifting cylinder failure. E14- oil pump fault.
5.	Steering system (G6)	E19- steering block failure. E20- steering tie rod failure.
6.	Electrical system (G7)	E15- contact switch & wiring failure. E16-alternator failure. E17- emergency failure. E18- battery failure.

5.5 Probability of Unavailability of Surface Miner

In this section, probability of unavailability of the surface miner has been carried out. There is need to know probability of occurrence of all the basic events which lead to the failure of top event. In Fig. 15 top event (G1-breakdown/unavailability of surface miner), intermediate events and basic events probability of occurrence have been evaluated and the value of breakdown/unavailability probability of the surface miner is approx.7.024%.

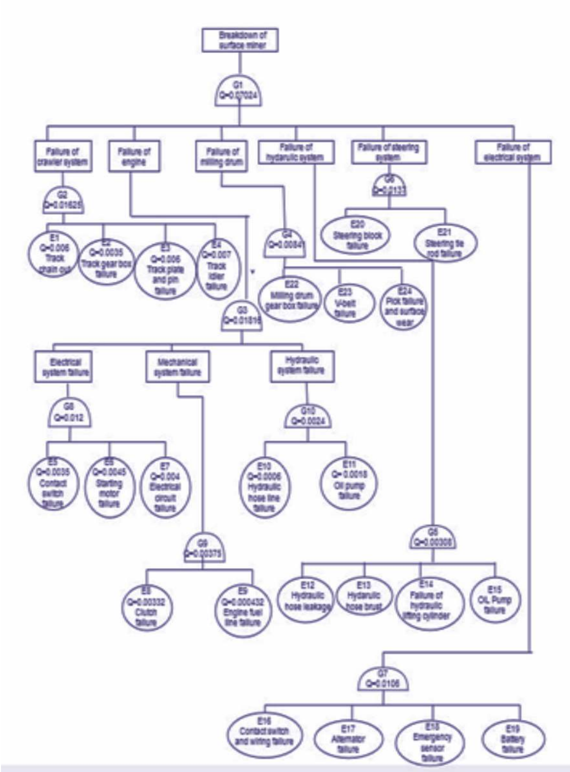

Fig.15. Probability analysis of surface miner

6. RESULTS, RECOMMENDATIONS AND IMPLEMENTATION AT MINES

In this part, we discuss the Results and recommendations-based solutions and their implementation.

6.1 Results of Failure Analysis

The analysis was carried out and results of this analysis are explained. In this section, these are discussed to provide suitable solutions for improving the performance of the machine.

6.1.1 Results from failure analysis

Under this analysis, results from data analysis, FMECA and FTA are discussed. The main purpose of breakdown data analysis was to find the critical systems of machine.

Table.14. Results from data analysis

Ranking of system in terms of criticality	System descriptions
1	Crawler system
2	Engine assembly
3	Electrical system
4	Hydraulic system
5	Milling drum system
6	Steering system
7	Engine cooling system

The main purpose of FMECA was to find the critical systems of machine and critical failure modes on the basis of their Risk Priority Number (RPN).

Table.15. Results from FMECA

Sl.no	System description	Critical mode of failure
1.	Crawler system	-Track chain out. -Track pin and plate failure. -Track gear box failure
2.	Engine assembly	-Starting problem. -Engine clutch failure.
3.	Electrical system	-Electrical switches and wiring failure. -Emergency sensor failure.
4.	Hydraulic system	-Lifting cylinder failure. -Oil pump failure. -Hydraulic hose failure.
5.	Milling drum system	-Milling drum gear box failure.
6.	Steering system	-Steering block failure.
7.	Engine cooling system	-Engine high temperature observed.

The main purpose of FTA was to find the root causes of failures and probability of unavailability of system. The Fig. 14 shows the basic failure events while these minimal cut sets of system are tabulated in Table.13 with probability of unavailability of the surface miner is 0.07024.

6.2 Recommendations

6.2.1 Technical

The main purpose of technical recommendations is to reduce the unplanned breakdown, mean time to repair, and enhance the production out of the surface miner. These recommendations are direct outcome of failure analysis of surface miner. The following recommendations are identified and described below:

1. Proper maintenance, planning and control to be needed: After doing the breakdown data analysis, It has been observed that some systems of the surface miner are very critical (i.e. having high failure rate) and it has been also found that each critical system having particular critical modes of failure. So, by controlling or reducing the occurring of these critical modes of failure, it will be easy to control over the unplanned breakdown of machine. For more detailed, please refer to FMECA Tables 7-12. All critical modes of failures are listed in Table 16

Table.16. Recommendation for critical failure modes of the surface miner

Crawler system	Track chain out	- Check track tension - Avoid oversteering
	Track pin, plate failure	-Check the quality of material before using it. - Avoid over tension in track. - Proper levelling of track area.
	Track gear box failure	-Proper levelling of ground to avoid the overload on gear box. -Avoid over tensioning of track.
Engine system	Starting problem	-During maintenance, check starting motor and its electrical connection like contact switch, battery, wiring etc. -Check Fuel level before starting the machine to avoid air lock. - Check Starting motor coupling.
	Engine clutch failure	-During the operation of machine, avoid overload by controlling the depth of cut.
Milling drum system	Milling drum gear box failure	-Weekly check lubricating oil level. - Check milling drum gear box bearing.
Hydraulic system	Lifting cylinder failure	-Check oil level before operating any hydraulic system. -Check hydraulic hoses and their routing during maintenance period.
	Oil pump failure	-Check oil level before operating any hydraulic system. -Pressure gauge sensor should be installed.
Steering system	Steering block failure	-Avoid oversteering. -Check Pressure inside st eering cylinder through pressure gauge.
Engine cooling system	Engine high temperature observed	-Check cooling oil level. -Check cooling oil pump. -Daily Inspection of Radiator water level and water pump.
Electrical system	Emergency sensor failure	-Check all sensor connection.
	Electrical contact switch, wiring failure	-Cover all electrical contact switch to prevent from duct dispositioned and it should be cleaned on regular basis. - All the wiring should be inspected on regular basis.

1. Availability of spare assemblies: From Table 6.4, it is observed that breakdown hours of the surface miner were high due to unavailability of spare assemblies of critical system. It is recommended that spare assemblies of critical system like engine, milling drum system, oil pump, V-belt, track gear box, track plate, input adopter etc. should be made available to avoid the longer waiting hours. After doing analysis, it is concluded that production loss due to unavailability of spare assemblies is very huge compare to total inventory cost associated with spare assemblies**.**

Table.17. Detailed of unavailability of spare assemblies

Date	Unavailable component	Actual repair time (hours)	Waiting time for spare part (hours)
1/08/2013	Engine	331	55
16/02/2014	Engine	213	69
15/12/2014	Milling drum gear box	157	48

2. Preparation of check lists: Proper check lists should be prepared for daily, weekly, monthly, and quarterly to inspect all critical components of surface miner. A check list helps to inspect all the components to avoid unplanned breakdown of machine. Moreover, the management should adhere to it so that benefits of check lists can be grabbed. For example, in Table 6.5 a format of weekly check list is shown for crawler system. In same way, the check list of other system can be prepared.

Table.18. Weekly maintenance check list for the surface miner

WEEKLY MAINTENANCE CHECKLIST FOR SURFACE MINER		
For the Week From: -	**To:-**	**Date of Inspection :**
Name of supervisor:		**Name of site engineer:**
Component	**Check points**	**Status / Remarks**
Crawler system		
Crawler hydraulic motor system	Check the hydraulic motor unit noise	Yes / No
	Check hydraulic motor unit for any damages	Yes / No
	Check oil temperature and oil level	Yes / No
	Check the surface of hydraulic motor unit for excessive heat	Yes / No
Crawler track chain	Check the track pin for any damage	Yes / No
	Check the idlers for any damage	Yes / No
	Check the track plate for any damage	Yes / No
Crawler frame structure	Check track tensioner for any damage	Yes / No
	Check track wheel for any damage	Yes / No
	Check frame structure for any damage	Yes / No

3. Use of standard components: During replacement of any components, the substitute material should be of standard quality. If material is of standard quality, it will work for longer time compare to low grade material which reduces the rate of unplanned breakdown of surface miner.

4. Proper supervision: It has been observed that there is lack of supervision of surface miner. So, this needs to be implemented for the machine.

6.2.2 Administrative

The main purpose of administrative recommendations is to improve the output or performance of machine by proper utilization of available hours of machine. These recommendations are direct output of performance analysis of machine and these are totally controlled or implemented by the management. The following recommendation are identified and listed below:

1. Performance based incentive for supervisor and workers need to be implemented: It has been observed that there is no system available to measure the performance of supervisor and workers to boost up the confidence among the workers and supervisor who are really doing good job. There is need to frame the performance rating system to encourage the good work of supervisor and workers that improve the performance of machine. This performance-based incentive should be based on a feedback system.

2. Employing extra operators: The main reason for low utilization of machine is due to absentees of operators, there is need for extra operators. If some of operators are absent, extra operators can operate the machine which will lead to reduce the idle time of machine and thus increase the output of the machine.

3. Curtailed lunch and tiffin break times: It has been observed that machine is not getting utilized properly due to higher lunch and tiffin time for operators and workers which leads to low utilization of available hours occurred. So there is need to optimize the lunch and tiffin time in such manner that which is good for both management and workers.

4. Engine fuel availability: Many times, it has been observed that machine was not operated due to unavailability of fuel, which lead to the low utilization of available hours.

5. Need for proper infrastructure like drainage system, road etc.: During rainy seasons, it has been observed that water gets flooded in whole machine operating area and there is no arrangement available to pump out flooded water from operating area. Due to this reason machine cannot be operated and it leads to increase in the idle time of machine. Similarly, if proper road or approach is not available, it will be very difficult for maintenance department to shift the material from store to machine for repairing purpose. This leads to increase in the repair time and causes low output.

6.3 Implementation at Mines

The suggested recommendations can help to enhance the performance of surface miner, if there is effective implementation at mines. These suggested recommendations can be implemented on short- and long-term basis. Short term basis recommendations need to be implemented immediately, while long term basis recommendations will take longer time to plan and implemented. The recommendations for implementation at sites is given in Fig.6.1.

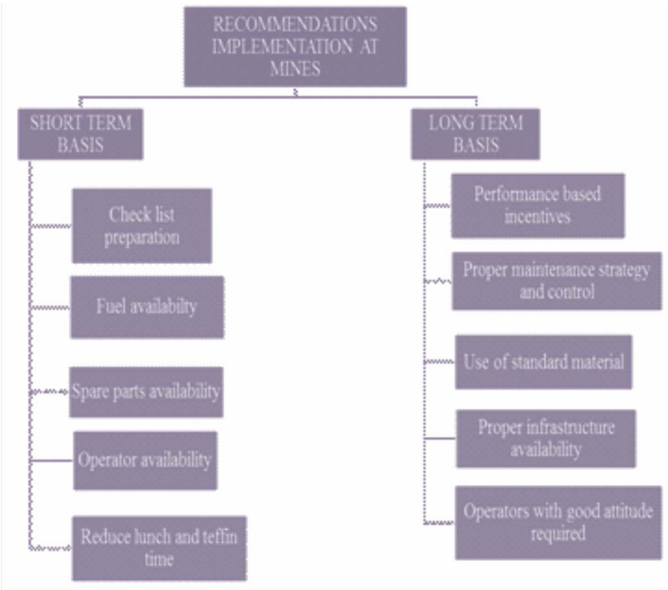

Fig. 16. Recommendations implementation at mines

7. CONCLUSIONS AND SCOPE OF FUTURE WORK

7.1 Conclusions

Some important conclusions from the present study are:

The study shows that data analysis, FMECA and FTA are suitable alternative for analyzing the failure analysis of mining equipment. In this project, the study of unit 15 of 'L&T Surface Miner KSM 303' was carried out and their breakdown and operational data were collected. On the basis of data, Failure analysis was carried out and results were discussed with emphasis on its delivery of root causes of unplanned breakdown and low performance of the surface miner.

The result ranked the parts of surface miner in order of severity effect due to failure. In this process we identified the most critical part of the system. In failure analysis, critical failure modes of different systems were identified and listed. The unplanned breakdown of surface miner can be reduced to a great extent by selecting the proper maintenance procedures and planning, following proper check list, using standard material, having proper supervision and good skilled workers and supervisor, etc. that control the critical failure modes of critical systems.

In addition, with this, framing and implementing of performance-based incentives for workers and supervisors can also be an effective tool to reduce unplanned breakdown of the surface miner.

7.2 Scope of Future Work

Based on conclusions and issues, the proposals for future research work are stated below. The further research work on the surface miner can be extended to the reliability and maintainability analysis. In reliability analysis, there is need to find out failure probability distribution (logarithm, exponential, Weibull etc.) followed by breakdown data. Once the nature of probability distribution of breakdown data is determined, the probability of occurrence of failure at particular time can be determined which can further help maintenance engineer to plan maintenance. In maintainability analysis, there is need to find out grey areas attributed to poor maintainability. This will proceed direction to improve it.

The further research work on comparison between running life and manufacturer's standard life of different components can be extended in future. The further research on development of the model for the decision diagram on maintenance strategy can be extended.

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