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Methods for Risk Management of Mining Excavator through FMEA and FMECA

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ABSTRACT

Management of maintenance systems in the mining industry is an important condition for their operation. If we recognize the need for risk analysis and management of individual maintenance system, it can generate potential overall efficiency and effectiveness. Special importance for the realization of the objectives of the mining industry belongs to redesign, system harmonization between the various technical structure, standardization, technical diagnostics, analysis of different levels of criticality with variant selection and application of optimal solutions. The potential for the destruction of the complex maintenance systems are a reality in the mining industry and their expression in various applications is a realistic one.

For different aspects of the analysis it is possible to decrease risk index range from the threshold to the range of high and low threshold of moderate and acceptable risk. Application of FMEA (Failure Mode and Effect Analysis) and FMECA (Failure Modes, Effects and Criticality Analysis) methods are used to manage risk related to the initial phase of defining the prediction of all possible risks, risk factors and RPN budget priorities. Some risks can be grouped according to the type of errors that occur due to their realization. For effective risk analysis and implement measures to reduce their need is and competent team. No matter what the risks involved, FMECA method can reliably estimate the possibility of their implementation with a satisfactory degree of flexibility and compatibility.

In this paper an attempt has been made to develop an effective maintenance methodology of excavator such that the maintenance cost is 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 depends 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. Based on the above factors maintenance plans are prepared.

This paper discusses a risk management strategy system for Optimal Maintenance Program (OMP) of excavators. The OMP includes functional analysis method of FMEA and FMECA. To develop a successful operation system, it is first necessary to create a risk management program. A prudent management program is one that ensures safety and is environmentally and economically responsible.

Keywords: *Diagnosis, FMECA, FMEA, Maintenance, OPM and Risk Management etc.*

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I. INTRODUCTION

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 analyze 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.

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 are typically generated from a top-down or deductive approach, which does not require the use of a supporting FMECA analysis.

II. 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 behavior 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 behavior of the system, or whether his behavior under load in real operating conditions in accordance with the prediction of the designer.

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:

- Development of methodology for systemic risk analysis of technical systems;
- Developing a methodology for assessing the impact of all identified aspects of the destructive potential of technical systems in operation;
- System analysis, needs assessment for partial or complete redesign and modernization;
- Defining requirements and choice of technical risk management systems;
- Configuration management process technical risks in mining;
- Provide competent human resources for multidisciplinary work on risk management.

III. TECHNICAL PARAMETERS FOR COAL MINING

Surface coal mining is a very complex technical system. Their technical parameters are blend of technical, electrical and electronic units. Excavators are considered as one of the most complex machines and characterized by continual development and modernization during their lifetime. Equipment is heterogeneous, diverse and dispersed and located in real-exploitation sites. The continued growth of technology and the possibility of constructing a wider application of these excavators digging very hard and dissimilar materials and they work in extreme weather conditions.

IV. DEPENDABILITY, AVAILABILITY AND MAINTAINABILITY

Dependability concept has been introduced through ISO-IEC standards as the most complete concept that presents the most complete quality of service measure. Dependability includes availability performance, as its measure, and its influencing factors: reliability performance, maintainability performance, and maintenance support performance. Implementation of dependability concept was developed in detail in IEC-300 standards where dependability objectives were defined and principles of dependability management.

In the analysis of reliability and maintainability based on probability theory, these characteristics are expressed quantitatively, i.e. as the probability function for failure likelihood in the case of reliability or as the probability function for duration of selected maintenance operation in the case of maintainability. In these analyses, especially for complex mechanical systems, (excavator) problems related to systems' structure definition in reliability sense, characterizations of incomplete failures and similar problems can arise as serious obstacles in definition of probability functions.

Dependability was introduced to be the most complete concept that describes availability of considered technical system, i.e. presents the most complete quality of service measure. Implementation of dependability concept in essence includes information about system behaviors during up and down-time with regards to design and logistic indicators (concrete information related to reliability, maintainability and maintenance support) as it were defined in ISO–IEC 300.

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 maintenance) in terms of ways in which problems (failures, errors, conflicts, concerns) can happen.

VI. APPLICATION OF FMECA

Practical implementation of the FMECA method assumes the formation of FMECA team. Total required knowledge for the application of methods. FMECA does not have only one function in the company. This fact has created a need to evaluate the technical

- Determination of all possible kinds of failure on the product that may arise as a result of errors in the design of products or processes;
- Determine all the possible consequences of each potential type of failure;
- Determine all possible causes of each potential type of failure;
- Definition of control and diagnostic measures;
- Determining, for each pair of "possible type of failure – possible cause of failure types,

The following basis for assessing the degree of criticism:

- Probability of occurrence of types of failures (Probability of Failure-PF);
- Weight effects of types of failures (Failure De Merit Value- FDV);
- Probability of detecting types of failures (Probability of Failure Remedy-PFR);
- With the evaluation of the base, usually done using the scoring scale of 1 to 10;
- Assessment of the degree of criticism (Risk Priority Number - RPN) for each pair of "possible type of failure-possible cause of failure types, using 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.

VII. APPLICATION OF FMEA

In the knowledge engineering phase: If we take the case of five different types of excavators, however, all are very similar, if not identical. The knowledge engineering phase of this research involved the identification of the different main components and corresponding failure modes for excavators: Engine, Pump, Actuators, Swing system, Coolant. 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 centered maintenance analysis FMEA (Failure Mode and Effect Analysis) sheets. We can take the numeric parameters like: Severity (S), Occurrence (O), Detection (D) and risk priority number (R), given for each failure mode and applied to the five different types of excavators.

Table I FMEA Worksheet

System in analysis- Engine, Pump, Actuators, Swing system, Coolant

COMPONENT	FAULT	CAUSES	REMEDY
Engine	High Oil Consumption (Determine from engine record)	External leakage Leakage for turbocharger or supercharge Head Gasket Leaks Oil Pan Leakage Leakage through filter spout Improper oil level	Identify Attend to turbo charger bearing Replace head gasket Tighten loose drain plug/replace Check & replace the filter spout Correct the oil level
Pump (or Oil Pump)	Low oil pressure. Pressure ranges from 0.35kg/cm^2 to 1.35kg/cm^2 at low idle 2.7 kg/cm^2 to 4.75 kg/cm^2 at high idle, when the pressure is below this limits, we have low pressure.	Oil level may be low. Delay in changing oil. Manufacturing of regulator Excessive leakage from bearing and bushes.	Pour oil up to the desired level. Change the oil as recommended. Correct/Replace the regulator. Change the bearing bushes.
Pump (or Oil Pump)	High oil pressure(When the oil pressure is above as indicated in No. 2)	Wrong grade of oil used. Malfunctioning of regulator. Improper bearing assembly Sludge or dirt in the oil pressure. Piston pulling nozzles partially choked.	Use proper grade of oil Check/Replace if required. Re-assemble the bearing correctly Clean the oil pressure. Clean the nozzle.
Actuators	Malfunction in actuator system	Reduction in pump flow rate. Check for fuse of the torque control solenoid valve. Check for relief valve. Check for loose harness connection beforehand.	Check for primary pilot pressure. Install pressure gauge to torque control solenoid valve output port. If pressure is not normal, clean and adjust pilot relief valve. Check for continuity between harness end and machine end.
Swing Systems	Swing is slow or unmoving.	Faulty pilot system or the main circuit Faulty pump control pressure Faulty swing release pr. Faulty swing relief pr.	Check the pilot or the main circuit. Regulate pump control pressure. Check for swing parking brake release pressure. Adjust swing relief pressure.
Coolant	Malfunction of coolant level indicator	Check that indicator light is not burned out. Check all the other indicators work correctly Check that machine is parked on level surface. Check for loose harness connection beforehand.	Check/Replace if required. Check the other indicator by removing connector from coolant level switch. Check or parked at the flat/uniform level surface. Check for continuity between monitor harness end connector terminal and vehicle frame.

Table II Critical failure analysis based on FMEA worksheet

System in analysis- Engine, Pump, Actuators, Swing system, Coolant																				
	EX 110				**Z AXIS 120 H**				**Z AXIS 220 LC**				**Z AXIS 470 H**				**EX 1200-5D**			
FAULT	**S**	**O**	**D**	**R**	**S**	**O**	**D**	**R**	**S**	**O**	**D**	**R**	**S**	**O**	**D**	**R**	**S**	**O**	**D**	**R**
1	4	1	1	4	4	5	1	20	4	3	1	12	4	1	1	4	4	3	1	12
2	4	1	1	4	4	3	1	12	4	1	1	4	4	1	1	4	4	1	1	4
3	3	1	5	15	3	3	5	30	3	1	5	15	3	1	5	15	3	1	5	15
4	2	6	1	12	2	6	1	12	2	5	1	10	2	7	1	14	2	6	1	18
5	7	1	1	7	7	1	1	7	7	3	1	21	7	1	1	7	7	2	1	14
6	3	1	1	2	3	3	1	9	3	4	1	12	3	1	1	1	3	2	1	6

Table III. Display the list of FMECA for a group of building materials to dig mechanism, methodological and analytical flow in the risk analysis of technical mining system

TYPE ANALYSIS, CONSEQUENCES AND CRITICALITY CANCELLATION-FMECA			The Supplier		
FMECA TYPE IN THE LIFE CYCLE					
FMECA Design	FMECA Process	FMECA Maintenance	Product: Excavator		
NECESSITY OF IMPLEMENTATION FMECA					
New element	Problem of process safety	Difficulties in the maintenance organization	Product code Z AXIS220LCx24/4x0(400kW)		
New product	Problem of process stability	Difficulties in achieving skills			
New method	Critical operations	Difficulties in managing the maintenance	Design	Date 15.08.2014	List/List: 65/10
Revised utility requirements	The problem of quality assurance	Difficulties in decision making			

CONSTRUCTION GROUP	UNITS	CANCELLATION			EXISTING SITUATION					PROPOSED CORRECTIVE MEASURES	RESPONSIBLE POSITION	BOOST STATE				
		Spices	Consequences	cause	Preventive measures	PF	FDV	PFR	RPN			Applied corrective measures	PF	FDV	PFR	RPN
The mechanism of digging and discharge material	Crawler assembly	Excessive wear of crawler	Dynamic rotor struck the crawler	Not adequate selection of assembly material	Chemical analysis and testing of mechanical properties of sample	5	5	1	25	No corrective action at this time	/	/	5	5	1	25
				The failure of the projected geometry of slewing gear	Probation following the wear(Mech. Engineer system)	5	5	1	25	No corrective action at this time	/	/	5	5	1	25
				Error in the installment of crawler assembly	Coupling & bushes are checked for crawler, slewing & cable reel motor	8	5	1	40	Better process control during assembly	Mechanical maintenance manager/ Head assembly workshop	Application of measuring & control	5	5	1	25
	Boom	Damage to discharge boom & rotary plate	The loss of oil in the gear box	No adequate installation & sealing element	Replace all broken & cracked buckets & cutting bows, badly worn out teeth	8	5	1	40	Better process control during assembly. The introduction of preventive/predictive maintenance	Mechanical engineer system. Mechanical supervision. Mechanical	Confirmation & control. Monitoring & control of data	5	5	1	25

The mechanism of digging and discharge material		Super structure hoisting winches for bucket wheel boom									Supervision. Review team to maintain					
				Inadequate quality of built material	Possession of a high quality material on the reserve. Inspect the brake drums	5	5	1	25	No corrective action at this time	/	/	5	5	1	25
The mechanism of digging and discharge material		Rope winch hydraulic assembly	Interruption of the mechanism of digging material	Error in installation of assembly associated components	Possession of the necessary & appropriate accessories & tools for assembly (assembly workshop manager)	5	8	2	80	Better process control during assembly. The introduction of preventive/predictive maintenance	Head assembly workshop. Review team to maintain	Application of measuring & control. Monitoring & analysis of the data	4	8	1	32
				Inadequate choice of material returned	Possession of high quality spare parts(head assembly workshop)	5	8	2	80	Better process control during production. The introduction of preventive/predictive maintenance	Process & final control of the manufacturer. Review team to maintain	Certificate materials (possession). Monitoring & analysis of the data	4	8	1	32

FOUNDATION FOR CHECKING LEVEL CRITICALITY			ASSESSMENT LEVEL CRITICALITY		FMECA TEAM
Probability of occurrence of failure PF	Consequences of failure difficulty FDV	Probability of detection failure PFR			Service
Almost never occurs 1	No impact 1	Virtually always reveals 1	Value score	RPN	Expert team for maintenance
Individual cases 2	Very little impact 2	Very high probability of detection 2			Review team to maintain
Very rarely 3	Weak influence 3	High probability of detection 3	Small	Less than 50	Mining follow-up service
Rarely 4	Negligible impact 4	Average probability of detection 4			Mechanical maintenance
Low probability 5	Discernible influence 5	Moderate probability of detection 5	Medium	50-100	Electrical maintenance
Average 6	Considerable influence 6	Small probability of detection 6			Laboratory for measurement & testing
Quite high 7	Major impact 7	Very low probability of detection 7	High	100-200	
High 8	Acceptable impact 8	Rarely is revealed 8			
Very high 9	Very serious impact 9	Very rarely is revealed 9	Critical	More than 200	
Almost always 10	Catastrophic impact 10	Practically does not reveal 10			

FMEA and FMECA sheets were prepared on the basis of overview of system failure data recorded in the month of May to July 2014 (Excavator Z AXIS 220LCx24/4x0(400kW)

VIII. RESULT AND DISCUSSION

Technical aspect of the problem analysis and critical failure of FMEA and FMECA method are confirming the real position of high risk thresholds on the technical system. Analysis of technical systems points to a specific destructive effects, according to an analytical view of each selected circuit. These have been detected in a technical sense and based on the factors presented by the possible harmful potential. Problems are most likely to occur to those of standard features that are atypical for a particular set or group of selected components in the sequence of projected technical characteristics of the system.

The mechanism for the transport of material input shaft gear belts, bearings fired damage, a consequence of the interruption of flow of material on discharge boom and rotary plate, the cause of the error in the installation of shafts and related components and low-grade embedded material. Preventive measures the possession of high quality spare parts, corrective measures is the reception quality of spare parts from suppliers. The improved condition index is 20 RPM and 25.

The supporting steel structure: super structure hoisting winches for bucket wheel boom, the damage is detected fired steel girders, a consequence of the increase in vibration and the cause of fatigue. Initial RPM is 250, degrees of extreme criticism. Preventive measures to control the service, and proposed corrective measures is a better process control during the service, specializing in testing services and the introduction of predictive/ pro-active maintenance. The improved state of RPM was 40 with an index.

The results of applying the method of FMEA and FMECA are shown only partially for some of the characteristic module. The analysis suggested a number of preventive and corrective measures with specific debit for realizing them. In the improved situation confirmed the initial hypothesis is defined it is possible to reduce the distances RPM range of acceptable risk index below the 50th The general conclusion is that it is possible to implement FMEA and FMECA method for monitoring the risk of criticism and analysis of technical systems in mining.

IX. CONCLUSION

The need for quality monitoring of technical systems in mining is explicit. Reduction of the total potential criticism by minimizing the destruction, which is measured by multiple applications and very often large scale damage and loss, it becomes imperative for management of the company. Analytics and critical analysis of methodological procedures, causes and consequences, presented in the paper shows that it is possible and necessary practical implementation of the FMEA and FMECA method of manufacturing practices mining. The presented results of the analysis indicate that the systemic approach can affect the overall reduction in critical and destruction and with the proper metrics and control as well as constant monitoring to ensure satisfactory quality of the projected level of technical performance of the system.

Data were recorded on reliability centered maintenance analysis FMEA (Failure Mode and Effect Analysis) sheets. For analysis purpose numeric parameters like: Severity (S), Occurrence (O), Detection (D) and risk priority number ® etc are considered for each failure mode and applied to the five different types of excavators.

Whereas, FMECA is a method with all these elements (requirements) represented in the standards. Through the method of FMECA lives purpose and spirit of preventive approaches to problem analysis and display of technique. By definition, the very process FMECA is a method for optimizing design, process, maintenance, through changes (re-engineering) to improve or eliminate any known or potential problems. FMECA method always recognize the link: R (t) = 1 - F (t), which means that reliability can never be 100%, and is directed towards reduction of the intensity of failure to achieve as close to the projected value of reliability. It remains a great place for a broad implementation and application of FMEA and FMECA methods in mining applications.

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