An Expert System for Predictive Maintenance of Mining Excavators and its Various Forms in Open Cast Mining

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Abstract: **The purpose of this paper is to develop an expert system for predictive maintenance of mining excavators and its various forms. These excavators are finding increasing applications in mining operations. Although, extensive data base and knowledge pool are available regarding maintenance, its methodology and concerned feed back mechanism, but no suitable or custom built expert system is yet available for specific mining machinery including excavators. Research and Development of a custom built Expert System is the need of the day because of large capital, productivity and risk involved with the mining excavators in a high capital intensive industrial scenario with acute sensitivity in the performance of such machines. This paper discusses an expert system for Failure Detection and Predictive Maintenance (FDPM) of mine excavators. The FDPM includes an expert system engine, a knowledge base, mathematical and neural network model for various fault detection and maintenance of excavators and its component and various sub-components. The FDPM system identifies, detect and locate the faults by various historical maintenance database, statistical fault analysis method, Genetic Algorithm and Artificial Neural Network. If the source of the one of the components under observation by the FDPM system, it accesses the integrity of the system components and predicts maintenance needs.**

I. INTRODUCTION

Open cast mining is the most common method of mine production in the world. In open cast mining, the required production is provided by various equipment groups, having different types and capacities. Mining excavators is a mega sized equipment, which requires a great investment. So, predictive maintenance is necessary and the whole maintenance methodology must be carefully analyzed for optimum maintenance of these equipments.

In this paper an attempt has been made to develop an expert system for effective maintenance methodologies of mining excavator and its various forms 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 for predicting equipment / component failures.

For component failure detection, which is performed continuously, we can use data similar to that monitored by protective devices to detect abnormalities in behavior.

The predictive maintenance accesses the condition of the component found to be the source of the fault so that, any required corrective action can be planned with least financial impact. The predictive maintenance also periodically accesses the condition of the equipment to detect the earliest onset of potential problem that causes the major fault. The FDPM system can provide an accurate prediction of any potential component failure on demand.

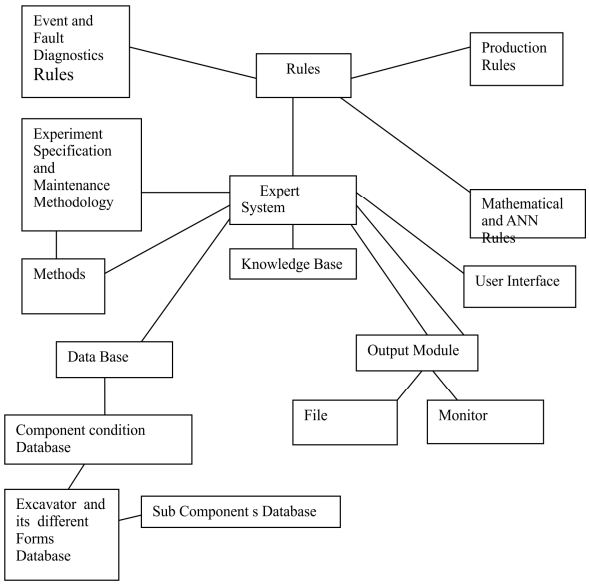

Fig. 1. Modules of Mine Excavators Expert System (FDPM) Structure

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II. EXPERT SYSTEM MODULE FOR FDPM SYSTEM

1. **Knowledge base** – The knowledge is usually acquired from documentation, existing computer information systems and human expert. A search strategy of expert system receives knowledge from storage and infers new knowledge from the base knowledge/working memory. The expert system has the ability to expand, modify, refine its knowledge base by means of leading module.

2. **Rule base**- Rules are determined according to maintenance activities and maintenance methodology. The FDPM system represents a compilation of rules derived to detect, classify and locate components fault in engine, hydraulic system, transmission system, break system, electrical and safety system etc. The rule base uses adaptive thresholds which are adjusted based upon these parameters.

   The rule base is developed using expert system development tool which has a predefined Consultation model, knowledge representation and inference engine paradigm.

3. **User interface** – Makes it possible for the user to supply information by means of prepared questionnaires regarding various components/sub-components of mine excavator about fault prediction and then necessary actions must be taken.

4. **Production rules** –These rules are constructed by using an IF-THEN format because the system support the modular structure. New rules can be added to the system whenever needed by means of editor facility in the expert system.
   IF-THEN – format takes into account the following six parameters / (Weight of Parameters): S (Safety) (1.5), IP (Machine importance) (03), MC (Maintenance cost) (02), FF (Failure frequency) (1.5), DL (Downtime length (01) and OC (Operating conditions) (01).
   Criticality Index :
   C.I= (S x wt. value of S)+(IP x wt. value of IP)+(MC x wt. value of MC)+(DL x wt. value of DL)+(OC x wt. value of OC)
   Scale for S, IP, MC, FF, DL and OC:
   81-100…Very High, 61-80…High, 41-60…Normal, 21-40…Low, 0-20..Very Low.

III. MAINTENANCE POLICY USED IN THE EXPERT SYSTEM

Weight values assigned to the relevant parameters considered in rule based system and the maintenance policy must be based on these rules.

Criticality Index	Maintenance policy	Mine Excavator components
>395	Predictive	Engine, Hydraulic and transmission system
280-394	Predictive	Break and Electrical system
<280	Corrective	Suspension, track and tyre.

5. **Databases-** Databases are generated regarding excavator database and its various forms, production capacity, equipment specification, production rate etc. Data is continuously and periodically monitored and selected data is stored in the databases and referred as historical maintenance database. Three categories of historical data is stored in the data base. The first category represents all systems data measured during the past 20 periodic monitoring sessions. Second category – for each periodic monitoring sessions in which a deteriorating components is detected is stored in the database. The third and the last category represents all system data measured during each continuous monitoring sessions in which an component failure is detected.

6. **Mathematical or neural network model** – These models are designed using equations or approximated functions which model the aging process or deterioration for each type of components and also for fault diagnostics for each type of components and sub-components. The ANN uses input and output pairs to dynamically describe the components fault and its responses to predict failure by means of learning process (back propagation algorithm).
   These models provides the capabilities of trending, recognizing changes within a complex spectrum and displaying methods of maintenance methodologies in actual operating condition at any point of time.

7. **Event and Fault diagnosis** – Subsystem analyzes system maintenance and estimated values to detect / predict the presence of component failure and its subcomponent failures. Data about the event such as duration of failure, spectrum, magnitude and frequency occurrence are used to localize and classify the source of the fault.

   After the probable cause is determined, the maintenance system accesses the sources of fault in the components/subcomponents, determining the

time to failure and recommends corrective action, if necessary.

8. **Component condition database** – Assessment of the present conditions of equipment is performed using techniques which range from sophisticated computer driven instrumentation to human sensing to predict failure and to economically perform maintenance only when a potential failure is identified and at a time convenient to the production schedule.

   The condition measurements display the largest change and response to a changes in mechanical condition. These characteristics allow for the identification and recognition of changes from normal condition.

   The results from time and various parameters of fault analysis/prediction of maintenance data is used to access component condition. Lastly, the level of maintenance data is used to access component condition.

9. **Output module** – With the aid of output module, the results are displayed on the screen and can either be printed or saved in a file for future maintenance / fault prediction.

Selection of maintenance plan:

In order to select the correct maintenance methodology for a mine excavator considering its capacity, equipment specification. Production rate and criticality index.

Giving proper importance to the above parameters a Rule base system (IF-THEN STATEMENT) is prepared for the maintenance plan.

Expert system for excavators

Case I : Engine Maintenance :

IF oil viscosity is low, IF mileage schedule is completed,
IF number of days has expired
IF filter paper condition has deteriorated
THEN change the oil filter, change the oil
IF life cycle of component has not expired
IF breakdown has not occurred in component
IF Heavy production schedule is not meet
IF Impaired functioning of component takes place
IF Component likely to fail

THEN go for scheduled maintenance ELSE

Sub-system : Overheating

If, temperature gauge is defective, the thermostat valve is not operating, water pump and fan belt is loose, pulley is misaligned, radiator line is chocked.
THEN,
Overheating of the engine
ELSE,
Radiator is washed with pressure and check the temperature gauge and check the belt tension .
OR,
If, external leakage in pipe line and leakage in turbo charger and leakage in head gasket and oil regulator is malfunctioning and leakage from bearing and bushes
THEN,
Overheating of engine and oil fumes from engine and excessive dark exhaust smoke
ELSE,
Check for cylinder head or gasket, piston rings or cylinder liners and check for rocker levers and shaft damage, check for push rod damage, check for injector cup damage, check for pressure search in full line, check for engine search.

REPLACE THE COMPONENTS WITH EXPIRED LIFE CYCLE
IF Impaired functioning of components.
IF Components not meeting the required performance standard
IF components lifecycle completion is nearer
IF condition monitoring for equipments of performance not satisfactory
IF Vibration level, noise level, temperature level is beyond acceptable limit
THEN
GO FOR MAJOR OVERHAULING.

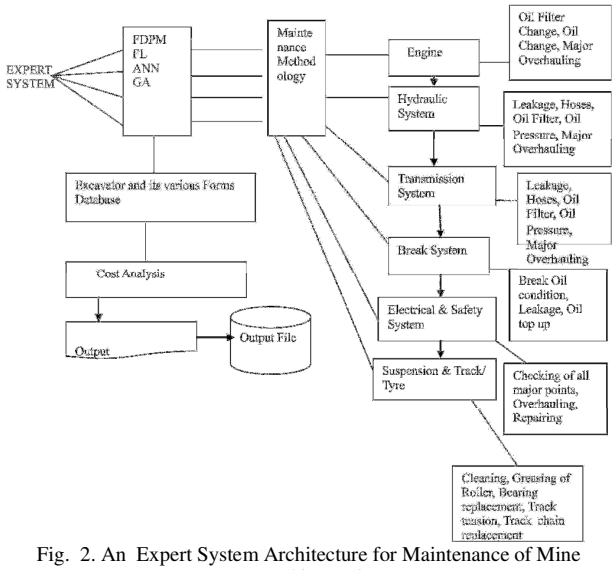

Fig. 2. An Expert System Architecture for Maintenance of Mine Excavators and its Various Forms

Case II : Hydraulic and Transmission System

If leakage in transmission system, pressure drop in pipe line, value is not operating, slippage in value, Barometer reading defective.

THEN,
Excavator condition is poor
ELSE,
Check for value maintenance,
Check for pressure drop,
Check for barometer defect
OR,
If Oil filter is defective, routine maintenance time for oil filter is over,
If oil viscosity is low,
If dust particle available in oil
THEN,
Hydraulic and Transmission system needs overhauling / routine maintenance

Similar rule based systems are prepared for Engine, Electrical and Safety system, Suspension and track etc. These sub-components maintenance activities are shown in the figure -2.

III. CONCLUSIONS

An expert system for maintenance of mining excavators (and its various forms) has been developed. These mining excavators are increasingly being used in open cast mining because of technological developments and because electrical energy is not being used. The system has equipment database obtained from manufacturers and mine specific data are entered into the system.

The paper has presented the framework for a new expert system for mine excavator's component failure detection and system related components and databases for use by the mathematical and neural network models which predict fault or deterioration in excavator components. The main aim is to select the optimum maintenance methodology to reduce the maintenance related cost as well as to reduce the unit production cost.

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