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Fault Diagnosis and Reliability Analysis of Load Transport Systems using Bayesian Belief Network Approach

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ABSTRACT

Coal is an important resource in Indian power sector. Due to the high demand of power for household and commercial activities large numbers of thermal power plants were established all over India. The quantity of coal required for these power plants is very large. For this reason, the amount of coal extracted should be sufficient to meet the demand. Opencast mining is one way of excavating the coal from earth. In opencast mining heavy machineries are used which includes dozers, scrapers, dumpers, shovels, trucks draglines etc. Among all these, dumpers play a vital role which is designed for carrying bulk material. Time loss in operation due to idleness, breakdown of dumper is no more affordable to mine management in recent years. Improper utilization of dumper can pose negative consequences on the production, productivity and production cost leading to loss of revenue. So it is important to analyze the performance of this equipment at regular intervals to achieve cost-effectiveness in excavation and transportation operations. Also, in order to maximize productivity and availability of dumpers in the field, the interruptions are to be minimized. In this paper, Bayesian Belief Network (BBN) approach has been used to analyze the reliability of the dumpers employed in opencast mines. BBN is a graphical model which has been used to analyze the failure probability of dumpers. It develops a fault diagnosis networks and evaluates the system by utilizing Bayesian Networks (BN) which incorporates the expert experiences through lateral linkages among BN nodes and weighting factors from historical data.

Keywords: Opencast mining, Dumpers, Reliability, BBN.

1. INTRODUCTION

Coal is a sedimentary rock which forms a major source of generating energy and also used as a fuel. The thermal energy which is obtained by burning coal is used in many industries like textile industries, for boilers, thermal power stations for electricity generation, cement manufacturing and steel production etc., Coal mining is a technique of extracting the coal from the earth's surface. Numerous techniques are available to draw the coal out from the earth's surface. Basically there are two common mining techniques (i) open cast mining, also known as surface or strip mining (ii) underground mining.

Open Cast mining is also known as surface or strip mining. Strip is a method in which coal is excavated by removing a seam of overlying soil and rock bed. Open cast mining is done where the coal is found near the earth's surface i.e., where the overburden is relatively thin (at less than 262ft.) On the other hand underground mining consists of digging shafts or tunnels into the earth to excavate coal. The depths may range from 1.5 km to a maximum of 3 km or more than 3 km.

1.1 Significance of dumpers Used in Open Cast Mines

Different equipment is used in open cast mines some of them are bucket wheel excavator, dumpers, dragline, bull dozer and drill rig. In this paper the failure analysis has been carried out on the dumpers. Dumpers (figure 1) are diesel powered vehicles which are used to carry the extracted coal in huge quantities. Dumper is a four wheeled vehicle with load which is skipped by the operator. Load carrying capacity of dumpers is expressed as tonnage. Generally dumpers are available in 60, 85, 100 tonnes.

Figure 1 Dumper

1.2 Reliability

"The reliability of an item is the probability that the item performs a specified function under specified environmental and operational conditions at and throughout a specified time." Quantitatively, reliability is the probability of success. Usually expressed as a function of Mean Time Between Failures (MTBF). In mathematical terms, the time to failure T, of an item, is defined as a continuous random variable. The reliability, which is a function of time t, will then be expressed as the probability that the time to failure T, is longer than the operating time t. This means that the reliability is the probability that the failure has not occurred at time t. Reliability is a special attribute that describes the dependability of a component. This means that the component consistently performs a desired function under certain conditions for a certain period of time in order to meet business goals and customer needs.

1.3 Objectives of the present study

This paper is focused to identify the failures and the probability of occurrences using BBN for the enhancing the effectiveness of maintenance. A suitable software may be employed such as GENIE for the analysis.

2. LITERATURE REVIEW

Parvanesh sarshar and Christofer [1] constructed a Bayesian network model for the evacuation of the ship during fire accident. In this model they divide the ship into different compartments like A, B, C, D…etc. They estimated the time to reach the exit location from the historical data. From the data they constructed the conditional probability tables for each compartment. In this model the most important factors that have significant influence on a rescue process and evacuation time are identified and analyzed. By applying the probability distribution of the considered factors collected from the historical data, the trend of evacuation time was evaluated and predicted using the proposed model.

Chaur-Gong Jong et. al. [2] carried out the fault diagnosis of hydro power plant using BBN approach. The diagnosis system starts with the formation of FT based upon the problem domain. The transform from multi-state FT to BN is performed to obtain basic BN. Furthermore, based upon experts' inputs lateral arcs among nodes are inserted into BN to derive a more sound BN. Finally, a logical transformation approach was developed in the study to convert the logic gates in FT into CPT in BN. The results of BN inferences were validated by a comparison with the reliability analysis based upon historical data of three hydro-power systems in Taiwan.

M. Neil, Fenton and S. Forey [3] applied BBN model to the military vehicles for predicting the reliability. They have shown that very large BBNs can be constructed in a modular fashion in a way that allows the overall BBN model to grow arbitrarily large. In this work authors have elicited very large subjective probability distributions from DERA relating to design and production process maturity using novel techniques. The use of causal assumptions in building the graph topologies and our automatic methods for generating NPTs has significantly improved the efficiency and effectiveness of BBN construction.

Muhammad Kashif Shahzad et. al [4] developed new BN model on the production line to provide feedback to technicians during maintenance, on possible failure modes and effects, if the expected criteria level is not reached. The proposed methodology demonstrates that efficiency of continuance actions by technicians has a strong impact on the subsequent risk, failure occurrences and ultimately on the equipment unscheduled breakdowns. This paper also concludes that providing feedback to maintenance personals on the consequences of their actions improves failure occurrences that have direct impact on the production capacities.

3 BAYESIAN BELIEF NETWORK

Bayesian Networks (BN) are increasingly used for the construction of system reliability models, risk management, and safety analysis based on probabilistic and uncertain knowledge. Similar to Fault Tree Analysis, BNs consist of both qualitative and quantitative parts. BN combines probability

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theory with graphic theory and is consisted of three major parts: Node, Connecting arrow and CPT. BNs are directed acyclic graphs, in which the nodes represent variables, arcs signify direct causal relationships between the linked nodes. [5] It can also display interrelated variables in a network by means of their cause and effect relationships. [6] In this formalism, propositions are given numerical probability values signifying the degree of belief accorded them, and the values are combined and manipulated according to the rules of probability theory. Each node represents a variable and has two or more possible states. The technique can make qualitative and quantitative deduction for uncertain outcomes by inferring the conditional probabilities in BN. BN has a higher efficiency and accuracy in uncertain inference, especially for complicated systems with highly correlated elements. [7]

4. DATA COLLECTION

Data collection has a prominent role in the reliability analysis. Insufficient data or incorrect data may yield improper results. Once the data has been collected, framing the methodology for the smooth conduction of analysis is necessary. Most of the systems in any industries consists huge production data so there will be a challenging task to handle it and understand it. Some companies may maintain this data or some companies may not, but to run a production plant effectively and efficiently the most appropriate data has to be monitored for the statistical analysis. The reliability analysis is totally concerned with appropriate data collection. Data related to load hauling dumper working at open cast mines at SCCL, Ramagundam has been collected. For this study quantitative data is based on raw data collected over a period of three years on twelve dumper systems. The actual data, used for analysis is formed by the raw data collection, processed by sorting and classification. The analysis deals the number of faults occurred in components and repairable time in the system.

The methodology used in this paper has been mentioned in the flow chart figure 2.

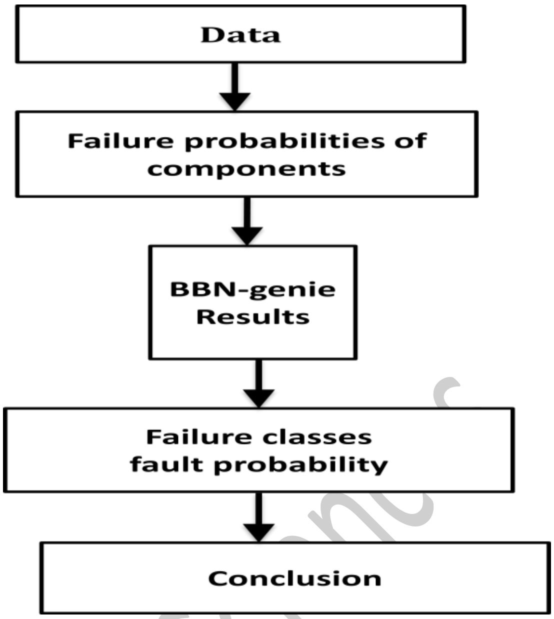

Figure 2 Flow chart

5. CONSTRUCTION OF BAYESIAN NETWORK

In each failure class, many failure modes exist, these failure modes can be termed as child nodes. These failure classes are the intermediate nodes which join to form a system called parent node. Based on this information on failure modes and failure classes and the Bayesian belief network is constructed.

Defined failure modes of each part as a child node make a connection with its failure class as its parent node. This procedure is framed for all the child nodes and parent nodes.[5]

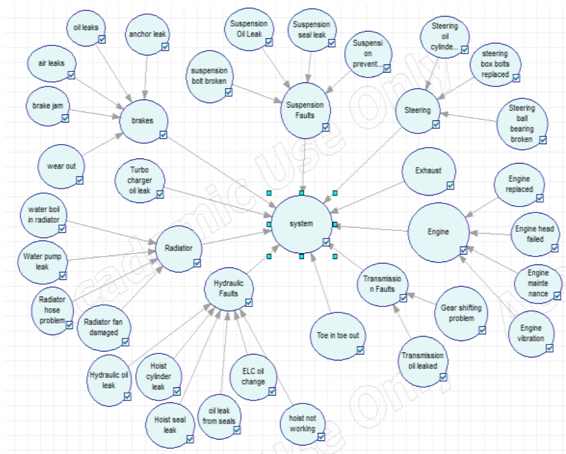

Figure 3 Bayesian Belief Network Diagram

6. FAILURE PROBABILITIES

The information which is obtained from the data table and also from the expert opinion the probability of the failure components is found. This is used as input data in the Bayesian belief networks. Based on the data fault probabilities of components obtained. Here some of the probability values are showing in below tables.

TABLE 1 Brake System

1(a)	Brake oil leak	Fault	0.007737
		No Fault	0.992263
1(b)	Air leak from brake	Fault	0.009671
		No Fault	0.990329
1(c)	Brake Jam	Fault	0.029014
		No Fault	0.970986
1(d)	Brake wear & air loss	Fault	0.011605
		No Fault	0.988395
1(e)	Brake Anchor Leak	Fault	0.014507
		No Fault	0.985493

TABLE 2 Suspension System

2(a)	Suspension Bolt Broken	Fault	0.011605
		No Fault	0.988395
2(b)	Suspension Oil Leak	Fault	0.116054
		No Fault	0.883946
2(c)	Suspension seal leak	Fault	0.034816
		No Fault	0.965184
2(d)	Suspension preventive repair	Fault	0.020309
		No Fault	0.979691

Table 3 engine faults probabilities

4(a)	Engine replaced	Fault	0.21978
		No Fault	0.78022
4(b)	Engine head failed	Fault	0.26374
		No Fault	0.73626
4(c)	Engine maintenance	Fault	0.01413
		No Fault	0.98587
4(d)	Engine vibration	Fault	0.00942
		No Fault	0.99058

These are the fault probabilities of failure components. These data has carried out for all the failure components in dumpers.

From the information of failure modes, the failure probability of each failure class is the probability of event A or event B or both of the events occurred. A,B represents failure modes.

P (A U B) = P (A) + P (B) + P (A ∩ B) for two multiple events (parent node consist two child nodes),

P (A U B U C)= P(A)+P(B)+P(C) – P(A∩B)-P(B∩C)-P(C∩A)+P(A U B U C) for three child events.

These are the ways to calculate the failure probability of failure classes for multiple events. The calculations are done in an excel sheet.

Example of failure class probabilities

In transmission faults, there are two events 6(a), 6(b) and their stated conditions given in the table.

TABLE 3 Evidences of Transmission System

6(a)	Fault		No fault	
6(b)	Fault	No Fault	Fault	No Fault
Fault	0.05	0.02	0.04	0
No Fault	0.95	0.98	0.96	1

In this manner evidences of all the failure components has been find out and these values are given as input in the GENIE software for conditional probability of multiple events.

The information from the tables is used to construct a network and also input data for GENIE software so that the results can yield for each failure class and the final system results can be found.

In a Bayesian belief network, if a parent node is having several sub-nodes (child nodes) and consists of different states, so it is very difficult to construct the shape of conditional probability

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tables. It is very difficult to club all the conditional dependent or independent events in BBN. To avoid all the complications to construct Bayesian belief network GENIE SOFTWARE is used. It avoids all the complexity of the problem domain and yields the results accurately.

7. RESULTS

The result of all the failure classes is obtained by stating the evidence of each failure modes of a component in GENIE SOFTWARE shown in the following figures. In below some of the results of system failures are shown.

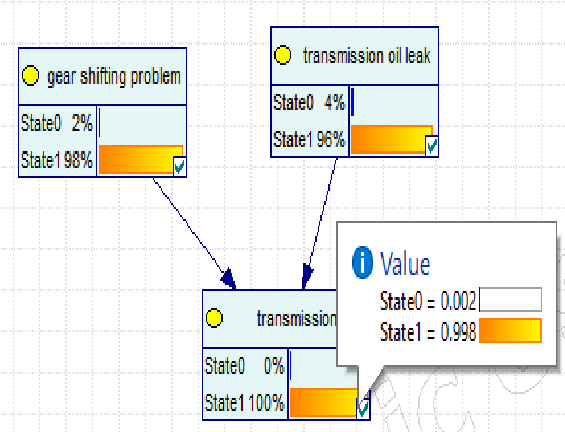

Figure 4 Evidences of Transmission failures

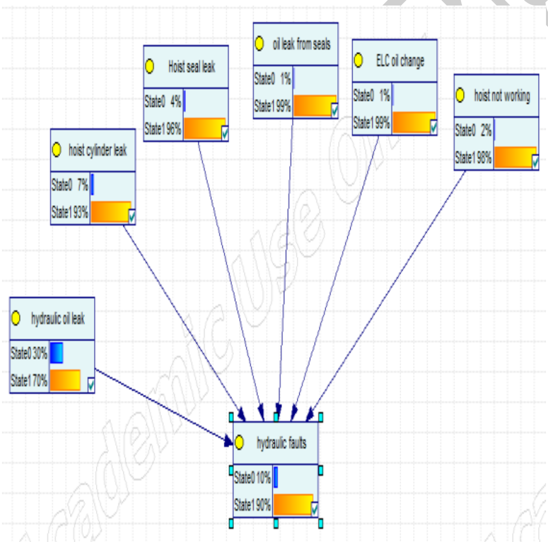

Figure 5 Evidences of Hydraulic failures

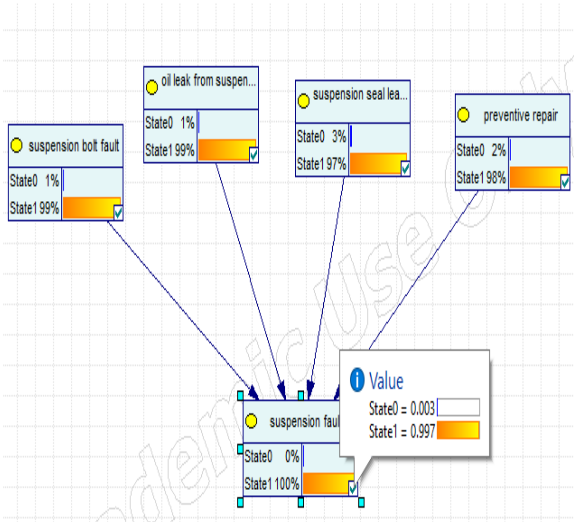

Figure 6 Evidences of Suspension failures

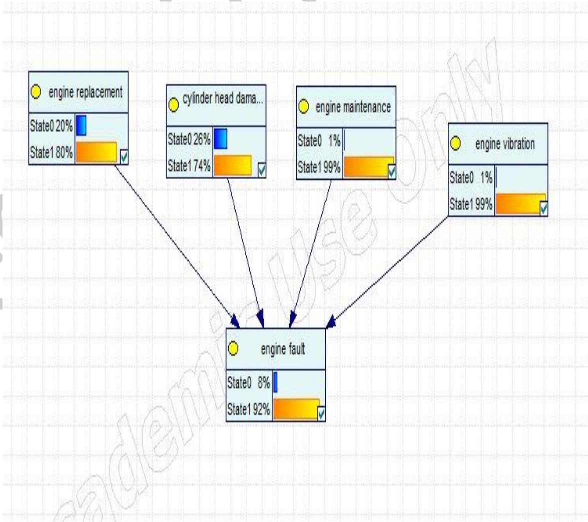

Figure 7 Evidences of Engine failures

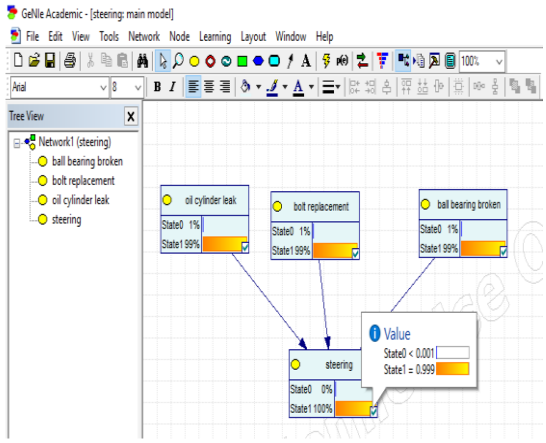

Figure 8 Evidences of steering failures

The failures of dumpers are scrutinized and categorized into failure modes and classes. Failure probability of failure classes by using GENIE software is summarized. From the results the discussions and conclusions are given below.

Table 4 Failure Classes of Dumpers

S.No	Failure Classes	Fault Probability
1	Brake System	1%
2	Suspension System	1%
3	Exhaust System	1%
4	Engine System	8%
5	Toe In – Toe Out	1%
6	Transmission System	1%
7	Steering System	1%
8	Hydraulic System	10%
9	Radiator System	1%
10	Turbo Charger	3%

8. CONCLUSION

This paper is developed to identify the failure classes and failure modes of dumper system by using Bayesian Belief Network. This information gives an analysis of failures and also recommends the corrective actions for the elimination of most risky failures in the system. The Bayesian network model constructed from the system analysis, executed conditional probability table (CPT) Values require for further calculations in GENIE SOFTWARE for analysis of failures of dump trucks. In general, the Bayesian-based diagnosis simplifies the maintenance process. On which appropriate preventive maintenance strategies can be designed. From the BAYESIAN network, constructed for dumper and their components failure possibility, the hydraulic system is the most sensitive component. This is evident for its fault probability. So corrective actions necessary for the hydraulic systems, further "engine system" and "turbocharger" can be evident the next sensitive components. It is required to continuing further prevention action based on the analysis. It helps to improve the system reliability and reduce the production loss and time.

The method uses to handle huge uncertain data in the production process systematically and results in the form of a percentage of overall system efficiency. This value will be the benchmark for all the upcoming operations for further trend analysis and forecasting.

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