RELIABILITY ANALYSIS OF DRAGLINE USING BAYESIAN NETWORK

Thesis submitted in partial fulfillment for the Award of Degree

Doctor of Philosophy

By

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Dedicated to my beloved parents and all my gurus who teaches me

तद्विद्धि प्रणिपातेन परिप्रश्नेन सेवया।

उपदेक्ष्यन्ति ते ज्ञानं ज्ञानिनस्तत्त्वदर्शिनः।।

(अध्याय 4, श्लोक 34, भगवत गीता)

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It is certified that the work contained in the thesis titled **"RELIABILITY ANALYSIS OF DRAGLINE USING BAYESIAN NETWORK"** by **"DEEPAK KUMAR"** has been carried out under my/our supervision and that this work has not been submitted elsewhere for a degree.

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I, **"DEEPAK KUMAR"**, certify that the work embodied in this thesis is my own bona fide work and carried out by me under the supervision of **"PROF. SUPRAKASH GUPTA"** from **"JULY 2016" to "DECEMBER 2022"**, at the **"DEPARTMENT OF MINING ENGINEERING"**, **Indian Institute of Technology (BHU),** Varanasi. The matter embodied in this thesis has not been submitted for the award of any other degree/diploma. I declare that I have faithfully acknowledged and given credits to the research workers wherever their works have been cited in my work in this thesis. I further declare that I have not willfully copied any other's work, paragraphs, text, data, results, etc., reported in journals, books, magazines, reports dissertations, theses, etc., or available at websites and have not included them in this thesis and have not cited as my own work.

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Lord Kashi Vishwanath may bless everyone with a happy, healthy, prosperous life.

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Contents

Preface

The ideas of reliability, availability, and maintainability aid in the development of methods for enhancing system performance and safety. To keep pace with the increasing demand for raw materials, the mining industryis rapidly expanding with intense mechanization and automation, which urgesdue importance on reliability, availability, and maintainability. While maintenance analysis deals with the cost implications across the operating life of the system or product, reliability analysis helps to manage system failures. Draglines are popular capital-intensive equipment in high productive surface mines and failures of a dragline have a significant impact on mine productivity. Draglines should have higher reliability for the smooth operation of opencast mines. This research aimed at the reliability study and failure diagnosis of draglines using a Bayesian Network (BN) model and identified the critical subsystems that affect the reliability. The reliability of the critical subsystem has been studied using the Dynamic Bayesian Network (DBN) model and the critical components of the subsystem are recognised.A preventive maintenance policy has been established for the components of the critical subsystems which helps to schedule the maintenance of the components and enhanced the overall reliability and performance of the dragline. The proposed methodology has been illustrated with a case study.

Failure data for the period January 2011 to April 2015of the dragline 'X', operating in an Indian surface coal mine, were collected for the present analysis. The dragline was decomposed into seven subsystems called bucket & accessories, dragging, rigging, hoisting, swinging, electrical auxiliary, and others. Data have been classified to calculate Time to Failures (TTF) data of each subsystem and component of the dragline. Statistical analysis of TTF data gives the parameters of the best fit theoretical distribution. The reliability of a draglines system has been evaluated using the Bayesian network model mapped from the Fault tree.The prior probability of each component (parent) node in the BN model is calculated using the parameters of the Weibull distribution's at time t=1hrs. The reliability of the dragline system has been estimated based on BN forward inference. The joint probability distribution for the developed BN model estimates reliability of the dragline system 62.03%, at t = 1 hour. The posterior probabilities are estimated from backward inference using the evidence on the BN model. . It can be seen that the dragging mechanism is the most critical subsystem having the lowest posterior probability (reliability) of 53.04%. While the electrical auxiliary is the second most critical subsystem, and the swing mechanism is seen to be the third most critical subsystem with a posterior probability of 68.35% and 77.08%, respectively. The accuracy of the BN model is 83.15% when it is only 71.07% in FTA. The dragging mechanism is the most critical subsystem to operate the dragline smoothly. The Dynamic Bayesian Network (DBN) model of the dragging mechanism has been mapped from the Fault tree. The overall reliability of the dragging mechanism is 84.29% at 1hr running of the case study dragline. It has been observed that the Drag motors contributes about 26% of drag mechanism failures, while the failures of power supply , drag brake and drag socket share 18.04% , 15.72% and 13.6%) respectively. The DBN model has been validated using a three-axiom-based validation approach.

Maintenance is a crucial part of ensuring the equipment operates normally. Maintenance policy has been framed for the components of the critical subsystem. An imperfect PM model for repairable components and an interval-based reliability-centred preventive replacement of non-repairable components are recommended. A cost rate optimization model has been used to estimate the optimum frequency of maintenance at a minimum cost rate, and the preventive maintenance interval is prescribed. . Using Monte Carlo simulation, it has been estimated that within a limited use time, the optimum maintenance frequency is 2 when the cost rate reaches a minimum, of Rs. 37548 per hr for drag motors. Thus the corresponding maintenance interval is 4000hrs. A replacement policy for a non-repairable component has been established using the characteristic life and MTTF of the component. This study suggests the interval between characteristic life and mean life of a component is a favourable time for opportunistic preventive replacement and scheduled preventive replacement thereafter. The characteristic life of the drag rope and chain has been estimated using the parameters of the best fit Weibull distribution and are 751.4251hrs and 433.3874hrs respectively while the MTTF value of the drag rope and drag chain are 4508.55hrs and 2600.25hrs, respectively. This study suggests an opportunistic preventive replacement of the drag rope between 751hr – 4508 hrs. Otherwise, components replace drag ropes after 4508 hrs of use to avoid undue down time. These results are useful information for inventory management.

List of Abbreviations

Artificial intelligence	AI
Artificial neural network	ANN
Bayesian network	BN
Condition based maintenance	CBM
Conditional probability table	CPT
Corrective maintenance	CM
Cumulative Mean Time to Failures	CMTF
Cumulative Mean Time to repairs	CMTR
Cumulative Number of Failures	CNF
Directed acyclic graph	DAG
Dynamic bayesian network	DBN
Dynamic object oriented Bayesian Network	DOOBN
Failure mode and effects analysis	FMEA
Failure modes, effects and critically analysis	FMECA
Fault tree	FT
Fault tree analysis	FTA
Genetic algorithm	GA
Heavy earth-moving machinery	HEMM
Hidden Markov model	HMM
Homogeneous Poisson process	HPP
Human and organizational factors	HOF
Independent and identically distributed	IID

Iot-based running time monitoring system	I
Machine-learning	ML
Markov chain	MC
Mean time between failure	MTBF
Mean time to failure	MTTF
Minimum cut set	MCS
Mutual information	MI
Non-homogenous Poisson process	NHPP
Northern Coalfield limited	NCL
Ordinary renewal process	ORP
Over burden	OB
Pair-wise comparison nonparametric test	PCNT
Preventive maintenance	PM
Probability density function	PDF
Reliability based maintenance	RBM
Reliability block diagram	RBD
Reliability, availability, maintainability and safety	RAMS
Renewal process	RP
Risk priority number	RPN
Support vector machine	SVM
Time to failure	TTF

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List of Symbols

Symbol	Abbrevation
R(t)	Survival function
$f(t)$	Probability density function
$\lambda(t)$	Failure rate function
$F(t)$	Failure function
E(T)	Mean time to Failure
H(t)	Cumulative failure rate
θ	Shape parameter
β	Scale parameter
P(X)	Probability of X components
$P(X_a)$	Parent node probability of X
P(E)	Probability of evidence
H(X)	Entropy of X
H(Y)	Entropy of Y
$X_i(t)$	ith Components at time t
α_i	Age reduction factor
ψ_i	Failure rate increasing factor
C_P	Cost of preventive maintenance
C_d	Cost of downtime maintenance
T_P	Total Preventive maintenance time
E(N)	Cost rate

C_{Total}	Total cost
T_{Total}	Total time

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