

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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2022

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

तद्विद्धि प्रणिपातेन परिप्रश्नेन सेवया।
उपदेक्ष्यन्ति ते ज्ञानं ज्ञानिनस्तत्त्वदर्शिनः॥
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ACKNOWLEDGMENT

First and foremost, from the core of my heart I would like to pay homage and tributes, to the great soul of **Mahamana Pandit Madan Mohan Malviya ji**, the revered founder of this beautiful temple of learning. His divine figure has always remained a source of courage, inspiration and motivation, a guiding light and a supreme example of patriotism and willpower in the form of Banaras Hindu University.

I would like to express my deep most sincere gratitude to **Prof. SUPRAKASH GUPTA**, Professor & Head, Department of Mining Engineering, IIT (BHU), Varanasi, for giving me the opportunity to work under his esteemed supervision. His constant encouragement and meaningful suggestions and constructive criticism during the course of my work have been of immense help in completing the thesis in time bound manner.

My deep sense of gratitude is due to all RPEC members **Dr. S.K. Palei**, Department of Mining engineering and **Prof. P. Bhardwaj** Department of Mechanical engineering, IIT (BHU). I am also thankful to all teachers of the department for their moral support, encouragement, and helpful suggestion during my research period.

I take the opportunity to thank the working staff and my lab colleague **Dr. P. K. Yadav**, and **Mr. Debasis Jana** of the department for their suggestions, which helped improve the work.

Last but not least, I would like to thank my beloved parents for always being there throughout my career. I must take the opportunity to give a special thanks to my wife (**Mrs Aishna Roy**). Without her constant inspiration and encouragement throughout this hard time, it was not possible for me to complete the work. I also express my debt to all of my family members and friends for kindly bearing with all my frustrations, desperation and negligence met them at different phases of this work.

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

Date: 24/12/2022
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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 industry is rapidly expanding with intense mechanization and automation, which urges due 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 open cast 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 2015 of 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 $t=1$ hrs. 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	Abbreviation
$R(t)$	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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