Chapter – 1
Introduction

1.1 Introduction

Due to the use of automation, embedded technology, multiple functions, hardware-software interfaces, and human and organizational factors (HOF), engineering systems nowadays are getting more and more complicated. Environmental impact, the cost of breakdowns and related downtimes, operational safety, and efficient maintenance are now major factors in system design. Engineering system failures in the past have caused the loss of life and long-term damage to the environment and property in places like nuclear power plants, aerospace, railways, process and manufacturing industries. To find solutions that either avoid or limit such unexpected breakdowns and enhance system performance, several researchers have been pondering these issues. Engineering systems must be designed, installed, operated, and maintained at the highest performance and safety standards with optimum cost. The ideas of reliability, availability, and maintainability aid in the development of methods for enhancing system performance and safety. As a result, modern, rapidly expanding sectors now require an estimation of 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.

Reliability assessment is everyone’s interest, from consumers to manufacturers. Interest in reliability estimation depends on the consequences of the failures. The failure of a component of heavy earth-moving machinery (HEMM) can lead to permanent damage to the components of a system, and the system may not perform its required functions at the desired level. The occurrence of failures involves increased downtime, reduced availability and increased maintenance costs. On the other hand, mining projects follow a specific operational sequence to produce coal or other ores. Therefore, failure of one of the operational sequences may consequently hinder the whole mining process. To achieve the targeted production, it is always intended to make the equipment operational and available in a production cycle.

India intends to increase its coal production to 1100 MT by 2025 to meet the country's rising fuel needs [1]. Surface coal mines account for over 93% of all coal output [2]. Production in surface coal mines primarily rely on HEMM like bulldozers, draglines, drill machines, dumpers, and shovels. Due to the high rate of over burden (OB) removal and maintaining high production rate with low cost of production, the majority of the large surface coal mines in India have switched from shovel-dumper system to dragline system for OB removal[3]. Draglines are capital intensive and failures of a dragline have a significant impact on mine productivity. Large draglines in the coal mining sector in Australia produce about $8,000 worth of output each hour[4]. Removal of OB using dragline effects low cost per cubic meter of OB removal and subsequently low cost per tonne of the mineral or coal production, in addition to a great degree of flexibility [5], [6]. Draglines can be used to rapidly and economically remove overburden and drop it into the de-coaled area [7], [8]. According to several studies, employing a dragline to remove overburden can save up to 30–50% on production costs compared to a shovel-truck[9] system. Draglines are favoured in opencast coal mines to achieve output goals economically.

Ageing, wear, and failures cause draglines to function worse over time, reducing their reliability and availability[10]. The chance of failure and downtime losses increases as a result of the unanticipated HEMM failures, which finally affect performance, lowers production and raise maintenance costs[11]–[13]. Draglines are the backbones of a highly productive surface mines, and their failures are exceedingly unfavourable for the economic sustainability of mining projects. When a dragline system malfunction, it may permanently harm the component or system and renders it unable to carry out its intended function. In industries: reliability, availability, maintainability and safety (RAMS) analysis are popular for analysis of failures, identifying significant failure modes and devising suitable counter measures. Therefore reliability analysis and maintenance planning for the various dragline components are highly desirable for enhancing their performance.

Statistical methods, reliability block diagram (RBD), fault tree analysis (FTA)and markov chain (MC) techniques have been used for reliability analysis in various industries since 1970. In the last two decades, Artificial intelligence (AI) has advanced significantly from a theoretical field of study to a useful technology with broad commercial applications. AI has been successfully addressing the difficulties in handling large range of data and variation in the nature of the problems. Numerous AI based machine-learning (ML) methods have been evolved[14], [15] to model complex industrial processes including failure process of large equipments. Several ML techniques like Artificial Neural Network (ANN)[16], Support Vector Machine (SVM)[17], Bayesian Network(BN) [18], Fuzzy Logic[19], Genetic algorithm(GA)[20] and data- driven hybrid models (a combination of multiple ML techniques)[21] have been used for performance analysis of various industrial equipments.

This research has developed a Bayesian Network (BN) model to study the reliability of a dragline using failure and maintenance logbook data. These data can provide insight into the basic nodes of the BN that make up the occurrence of failure and can be used to study the inter-dependability of subsystems and draglines. Bayesian network inference helps to diagnose the dragline's failure and identify the critical subsystems of the dragline. This work also include a Dynamic Bayesian Network (DBN) model for reliability assessment of critical subsystems, identifying the most critical components, and evolving a preventive maintenance model to undertake timely maintenance.

1.2 Statement of the Problem

The performance of a dragline is affected by the failures of its components. A sudden failure of any critical component will make the dragline inoperable, resulting in a significant loss of production, an increase in maintenance costs, and a decrease in machine performance. Additionally, failure of the dragline boom, bucket and other critical components might be catastrophic for anyone working near it or on it [22], [23]. Reliability analysis of the dragline system is not much investigated beyond the traditional statistical models, including the fault tree analysis (FTA) and markov chain models. While Bayesian network have not yet been sufficiently explored for the mining equipment reliability analysis. Bayesian Network models are computationally more precise to deal with the casual relation between the various components and subsystems. Also, Inference and diagnostic information propagation capabilities enable BNs to accomplish reliability estimation and critical components identification of dragline's within one model. This research thoroughly analyse the failure of a dragline up to the component level by split up the dragline into several subsystems and their components and deals with the effect of components failures on the corresponding subsystems and dragline. Therefore, every effort must be made to include the components in the reliability estimation to make the analysis more prescription specific. This will enhance performance of the dragline and continuous production can be achieved with improved reliability and availability avoiding the catastrophic failure of the equipment.

1.3 Significance and Novelty of the Research

Most of the research works on the reliability analysis of mining machine's are based on the traditional statistical methods, FTA, and markov chain model[24]–[26]. Limited research has been done on RAMS analysis of the dragline including studies on the scheduling of preventive maintenance or replacement[5], [7]–[9], [27]. Important studies on the performance analysis of dragline is presented in Table 1.1.

Table 1. 1Reported studies on the failure mechanism of various components of dragline

Dragline component/subsystem	Methodology	Contributors
main chord tubular joint of dragline	Weld profile and weld root gaps is measured using silicon imprint technique and feeler gauges.	Pang et al. [28]
bucket	Finite element analysis	Ridley and Algra [29], Azam and Rai [23]
dragline boom support strands	Visual examination and electromagnetic testing	Metcalfe and Costanzi [30]
Dragline system	Equivalent age method to estimate the reliability	Mishra et. al [5]
Front-end structure of dragline including.	Lagrange equations and finite element analysis.	Li and Liu [31]
Dragline system	Using traditional statistical method	Kumar D. et. al [8]
booms	Stress analysis	Dayawansa et al. [32]
Drag system	Fault analysis using BN model	A.Sahu & S.K. Palei [33]
Drag system	Fault prediction using ANN	A.Sahu & S.K. Palei [34]

Dragline component/subsystem	Methodology	Contributors
swing pinion shaft	Chemical analysis of materials from the tooth another shaft by using atomic absorption spectroscopy.	Ranganath et al. [35]

Table 1.1 shows that most research studies on the performance analysis of draglines primarily focused on failure and fracture analysis of the dragline's swing pinion shaft, bucket, and boom. Very few research studies has been reported on estimating the reliability and maintenance planning of the dragline using classic statistical methods, comparable age models, and other methods. Reviewing the published work on the reliability analysis of mining equipment, it was found that these studies fails to explore the causal relations between various events and equipment reliability which is an important consideration in countermeasure planning. To overcome these problem this study proposes to develop a BN model for the reliability analysis of dragline. Distinct advantages making BN more suitable than the traditional approaches is its explicitly representing the dependencies of events, updating probabilities, and coping with uncertainties. Probability updating abilities of Bayesian networks allow to input the failure information as evidence for updating the failure probabilities of any node, and then using Bayes' theorem, the posteriori failure probabilities of the sub-elements is calculated. This research displays a data driven reliability study of a dragline system with an extensive use of BN and DBN and identify the critical subsystem and components requiring attention for improving the performance of the dragline.

1.4 Objectives of the Research

This research aims to overcome the challenges to improve overall reliability and minimizing dragline failures by developing reliability analysis based sound preventive maintenance policies. The proposed method is expected to help in better understanding the failure occurrence and subsequent control of failures of the dragline system.

The elements of the main objectives are outlined below:

- ➢ Development of a BN-based model for reliability analysis of the dragline system using operational data collected from the field.
- • Failure Diagnosis of the subsystems and components.
- • Identification of the critical subsystem of the dragline
- • Model Validation through sensitivity analysis.
- ➢ Reliability analysis of critical subsystem using the Dynamic Bayesian Network.
- ➢ Development of the maintenance and replacement schedule for the dragline subsystem/component.

1.5 Research Questions

Based on the discussion in the previous sections and the research objective, the following research questions are posed based on the research objective:

RQ1 How can one incorporate the evidence of occurrence of some events in the reliability model?

RQ2 How do one develop Bayesian Network and Dynamic Bayesian Network models for the reliability analysis of a dragline system?

RQ3 How do one identify the most critical subsystem and components in dragline's performance?

RQ4 How can we improve the performance of the case study dragline?

1.6 Research Methodology

A dragline is a large and complex machine with numerous mechanical and electrical parts. Based on the past performance records and reliability figures of the various subsystems of the case study dragline, one of the most important subsystems was considered for further analysis. The reliability of the case study dragline has been analysed from the recorded operational data. For better understanding the failure, a dragline has been divided into subsystems and subsequently to components for reliability analysis.

A Fault Tree(FT) was developed to represent the failure of the dragline system graphically. For quantifying the FT, failure probabilities for basic events of the FT were assigned through analysis of operational failure data of the dragline. Collected field data were pre-processed and classified to obtain a set of time to failure (TTF) of each components. These TTFs data of each components were statistically analysed using the Isograph software and the best fit distributions were identified along with their parameters. Failure probability of the basic events of the FT at a time was calculated using the estimated parameters and the distribution. The time vs. reliability of the dragline system was studied using isograph software. Developed FT of the dragline system was converted into a BN following a mapping algorithm. Prior probabilities at a time of each parent node of the BN was calculated using the estimated parameter values of the best fit distributions. The prior probabilities of the parent nodes and the available evidences were inputed to the BN to calculate the posterior probabilities and hence the reliability of the components or subsystems of dragline system using the BayesiaLab [36]. This analysis helps to rank the subsystems based on their contribution to the dragline system failure and identified the most critical subsystem of the dragline system. To validate the results, sensitivity analysis was done using the Mutual information method.

For details failure analysis of the critical subsystem, DBN was used to study the time vs. reliability variation and identifying the critical components of subsystem. The result was used into the maintenance planning of the critical components for enhancing the overall reliability of the dragline system.

1.7 Outline of the Thesis

This thesis comprises of eight chapters, and the structure of the thesis is shown in Figure 1.1.

Chapter 1: Introduction

This chapter presents the general information of failure analysis, basic concept of reliability analysis of dragline, a background of the problem statement, significance of novelty of research, the significance of the research, the objectives of the research work, research questions, research methodology and finally, outlines the structure of the thesis.

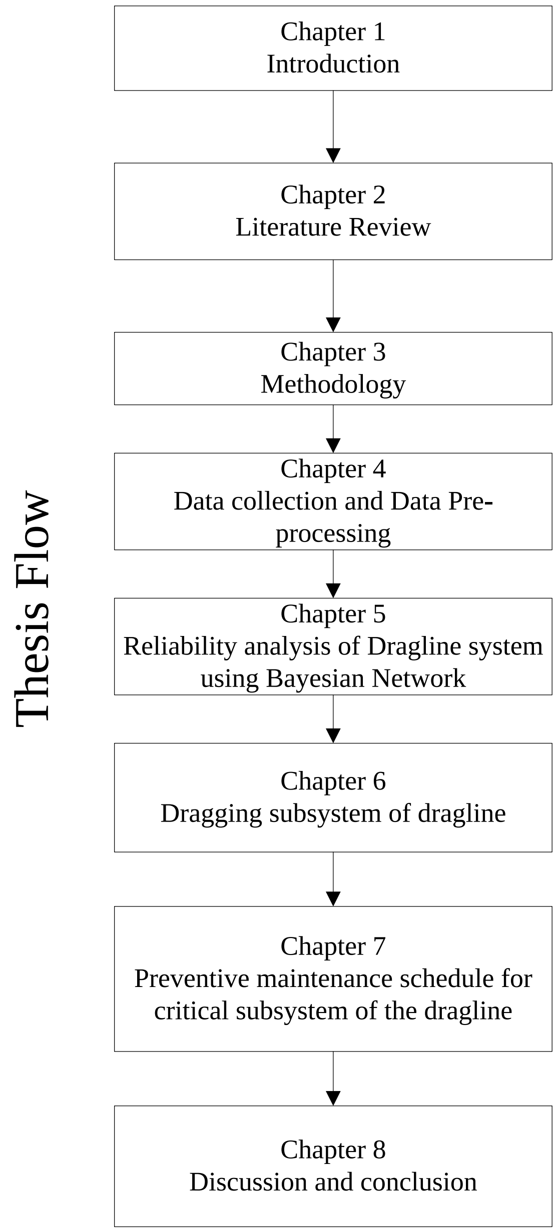

Figure1. 1 Structure of the thesis

Chapter 2: Literature review

This chapter reviews the comprehensive literature on performance studies of dragline and various reliability analysis approaches. A brief description of various reliability analysis methodologies is also incorporated along with their industrial applications.

Chapter 3: Methodology

This chapter presents the methodology to fulfill all the objectives of the research works.

Chapter 4: Data collection and data pre-processing

This chapter details the salient points of the case study mine and the dragline. It also enumerates the methods of data collection, preprocessing and preparation of the data for further analysis.

Chapter 5: Reliability analysis of Dragline system using Bayesian Network

This chapter contains detail information of FT and BN, establish the causal relationship between system, subsystem and component using conditional probability table (CPT). BN-based reliability analysis methodology consists of failure inference, failure identification, and sensitivity analysis. The chapter discussed on the result of case study of the dragline to estimate the reliability using BN. Finally chapter discussed about the critical subsystem of the dragline.

Chapter 6: Reliability analysis of Critical subsystem of dragline

This chapter contains detailed information about the dragging subsystem of dragline. This chapter also describes the parameters of DBN to estimate the reliability of the dragging subsystem. Also, the most critical components of the dragging subsystem are described. The chapter contains detailed DBN information and to establish the causal relationship between subsystems and components using CPT. The methodology of DBN-based reliability analysis consists of failure inference and sensitivity analysis. Finally chapter discussed about the result on DBN.

Chapter 7: Preventive maintenance schedule for a critical subsystem of the dragline

This chapter discusses on the maintenance of critical components of the dragline. Two maintenance models: i) for repairable components and ii) non-repairable components are suggested to improve the performance of the dragline. An imperfect preventive maintenance (PM) model for the repairable components like electric motor of the critical subsystem and .the interval-based reliability-centred preventive replacements for a non-repairable component like drag rope are recommended.

Chapter 8: Discussion and conclusion

Lastly, dissertation concludes at chapter 8 and scope of the future work has been discussed.