Chapter – 2

Literature Review

2.1 Introduction

This chapter a comprehensive literature review on the reliability and maintenance of the industrial systems. It incorporates the introduction to reliability and maintenance concepts, system reliability models and different maintenance policies, and recent studies on the reliability and maintenance of mining machines.

2.2 Reliability analysis across industries

Samuel T. Coleridge, an English poet, coined "reliability" in 1816 [37]. It is described as the likelihood that a system or component will carry out a necessary function for a predetermined time when operated under specified circumstances [38]. As early as 1900, the production unit began to emphasize reliability to increase mass production of standardized parts and components [39].

An appropriate mathematical model and analysis tool are necessary for the qualitative and quantitative reliability study. The preferred models accurately represent key aspects of the actual system, allowing analysis to forecast the future behavior of the system. Reliability Block Diagram (RBD), Fault Tree Analysis (FTA), and Markov chain(MC)[8], [21], [40], [41] are a few well-liked modelling methods for system reliability study.

2.2.1 Reliability Concept

Reliability is known as the probability that a component, product, or system will carry out its intended function or duty for a predetermined amount of time when employed under predetermined operating conditions [38], [42]. It is closely related to safety engineering in that both disciplines use standard methodologies for analysis and occasionally consult one another. System safety assurance, product life estimation, the projected number of failures, cost of system downtime, cost of failure, spare parts, repair tools, warranty claims, and staff are all essential aspects of reliability engineering[43]. The failure is viewed as a random event or phenomenon in reliability engineering. Therefore, failure probability varies between 0 and 1. The "intended function" is the foundation for reliability, which is defined as the average performance of a specific task without failure [38]. Reliability is generally applicable across a specific time frame which act as the independent variable and essentially indicates that a system has a certain probability of operating successfully before time t. The time frame to be evaluated may be the warranty period, the planned operation period, or another desired time frame. Cases may arises when the independent variable of a reliability function may be other than time. For example, the military might specify a gun's reliability for a particular number of rounds fired, but the car industry may establish reliability in terms of kilometres. In terms of use cycles, mechanical equipment may have a reliability value. Reliability is limited to operating under predetermined circumstances. It is impossible to create a system that can handle infinite circumstances; hence this restriction is required. The operating or working environment must be addressed at the time of design and testing [44] .

Reliability can be described by mechanical, electrical, thermal or other level of product property [45].

2.2.2 Common Mathematical Expressions in Reliability

The operational stability of systems is measured using probabilistic methods under the reliability concept. The reliability function is defined probabilistically. Equations 2.1 - 2.9 can be used to define the survival function R(t) and unreliability or failure function F(t),failure probability density function (PDF) f(t), failure rate function $\lambda(t)$ and their properties. Specifically, f(t) represents the time-dependent likelihood that a system would fail (Equation 2.1). It represents a failure frequency curve. Since it guarantees a particular failure state, as demonstrated in equation 2.2, PDF is equal to 1 in an indefinite time [38][46].

$$f(t) = \frac{dF(t)}{dt} = -\frac{dR(t)}{dt} \tag{2.1}$$

$$\int_0^\infty f(t)dt = 1 \tag{2.2}$$

Equation 2.3 states the chance of the system not failing in a random failure for time t. [38], [46]. This circumstance refers to the system's reliability (survival probability) at time t. As shown in equation 2.4, it can also be written as the area under the failure probability density function at the right-hand side of the time, t.[38], [46].

$$R(t) = P\{t_f > t\} \tag{2.3}$$

$$R(t) = \int_t^\infty f(t)dt \tag{2.4}$$

Since the sum of probabilities to survive and to fail is equal to 1, the failure function can be defined as in equation 2.5 [38], [42]. It is also the area under the failure probability function between time 0 and time t as given in equation 2.6 [38], [42]. Exponential, Weibull and lognormal distributions are commonly used distribution to describe f(t).

$$F(t) = 1 - R(t) = P\{t_f < t\} \tag{2.4}$$

$$F(t) = \int_0^t f(t)dt \tag{2.5}$$

Some statistical measures are frequently used in reliability studies to describe failure behaviours. Statistics aid in studying the shape of the density function and central tendency and spread of data. The mean, empirical variance, empirical standard deviation, median, and mode are the statistical measurements that are mostly used. Mean time to failure (MTTF), mean time between failure (MTBF), and failure rate(λ) ,are commonly used in reliability in addition to basic statistical terms.

Equation 2.7 provides a mathematical expression for MTTF [38]. It is sometimes notated as $E(t)$ which means mathematical expectation.

$$MTTF = E(T) = \int_0^\infty tf(t)dt = \int_0^\infty R(t))dt \tag{2.6}$$

Equation 2.8 can define MTBF according to reliability and maintainability standards like DEF-STAN-0040 and MIL-HDBK-217 [47]. T is the total operating time in equation 2.8, and n is the number of failures within the time period that includes the given running duration. If maintenance after failure restores the system to as good as a new state, then MTBF and MTTF are equivalent.

$$MTBF = T / n \tag{2.7}$$

Lastly, failure rate (λ) is one of the most used parameters to express system reliability and failure behaviour. This parameter gives the expected number of failures at time t,

$$\lambda(t) = \frac{f(t)}{R(t)} \tag{2.8}$$

Cumulative failure rate, H(t), in an interval can be obtained using equation 2.9 [48].

$$H(t) = \int_0^t \lambda(t)dt \tag{2.9}$$

2.3 System Reliability Analysis

A system is made up of several smaller subsystems that each perform a different task while working toward a shared goal. A reliability study can be carried out to examine the failure patterns of the entire system or just a few chosen subsystems. Each subsystem can be viewed as a separate system in and of itself.

Systems can be grouped into repairable or non-repairable. The non-repairable system cannot be restored after failure, and system has to be replaced with a new one. However, if a system is repairable, the whole system can be returned in functional conditions after failure via repair works. Generally, mining machines can be considered as repairable systems.

In recent decades, various qualitative and quantitative methods have been developed to study the reliability of the repairable systems. Reliability block diagram, fault tree analysis, Markov process and traditional statistical method can be utilised to evaluate the system reliability quantitatively, while failure modes and effect analysis, fault tree analysis are used for qualitative reliability analysis [49].

In recent times, complexity in machine design has increased manifold and huge financial investment, production pressure can't sustain frequent failure and repair to affirm high reliability and availability. Many machine learning methods have been developed to evaluate the system reliability. The regression method, Support vector method, fuzzy mathematics based method and Bayesian network model are to name a few that can be utilised to estimate the system reliability [45]

RBD is the network illustration of the system where various subsystems are linked in various configurations [7]. RBD is a conventional method to investigate the reliability with the help of functional and structural correlations between subsystems. Failure mode and effects analysis (FMEA) and failure modes, effects and critically analysis (FMECA) are used to evaluate the system reliability qualitatively. FMEA and FMECA analyse, evaluate and document the potential failure modes of the system and their effect on the system's performance [50]. Criticality of a system is defined from the Risk priority number (RPN) [51]. FMEA is applicable from beginning of system design, process design and system operation.

2.3.1 Fault Tree Analysis(FTA)

A system's undesirable condition is analysed using the fault tree (FT) methodology. This method of fault analysis is top-down and deductive technique. The data sample does not need to be normalised or scaled for the fault tree analysis. In the casual analysis of the system, the FT is utilised to describe the connections between a significant system event and its causes using Boolean logic [52]. Additionally, it is employed to track and manage how well complex systems operate in terms of safety. Numerous applications, including two-stroke marine diesel engines [53], nuclear power plants [54], longwall shearers [25] , air handling units [55], and belt conveyor systems [56], make use of the FT analysis. The disadvantage of FTA is that it is a time consuming process and requires more intricate calculations than other fault analysis techniques. The FTA is particularly highly sensitive to the change in the input data and results a big change in the decision tree's structure, leading to model instability. Mahmood A.Y. et al.[57] evaluated the FTA and Fuzzy FTA methods for dependability, maintenance, defect, and risk analysis of various machines in 2013.

2.3.2 Markov Analysis

Markov analysis is a mathematical modelling approach in which failure states are dependent only on the current state of the system[58]. The transition probability is not dependent on the past history of the system. A transition matrix correlates with the instant past state and future state with constant failure or repair rate[59]. Many studies have been done through markov analysis to estimate the reliability, availability and maintenance of mining machineries like LHD machine[60], tunnel boring machine [61], vertical drilling machine[41] and horizontal rotary drilling machine[62].

Table 2. 1 Important works on different relibility models

Sl. No.	Application area	Methodology	Authors
01.	CNC	Reliability analysis of CNC turning machine using maintenance data	Patil R. K. et al. 2017[63]
02.	Civil Structure	Reliability analysis of the bridge construction using fuzzy fault tree analysis	Pan and Wang 2007[64]
03.	Medical equipment	Quantitative analysis of Hypothetical Cardiac Assist System using dynamic fault	Merle et al. 2016[65]

		trees with structural functions and Monte Carlo method.	
04.	Mining equipment	Reliability estimation of mining equipment using the RBD method	Dhillon 2013 [49]
05.	CNC machine	Reliability analysis, including the mesh network, for improving the overall performance using the RBD method.	Lin et al.2010[66]
06.	Oil and gas industries	Reliability and Risk Evaluation of a Port Oil Pipeline Transportation System in Variable Operation conditions using RBD.	Soszynska J. 2006[67]
09.	Chemical industries	Reliability forecasting using the support vector regression.	W. Zhao, Tao, and Zio 2013[68]
10.	Diesel Engine	System reliability forecasting using the SVM and GA estimates the parameters of SVM.	Pai 2006[69]
11.	Mechanical Structure	Reliability analysis of mechanical structure with random stress and random strength using fuzzy linear regression method.	Bing Li et al.2000[70]
12.	Medical Diagnosis	Reliability of diagnosis method for brain cancer using the linear regression and synthetic data method.	Wang and Dinse 2011[71]

2.3.3 Bayesian Network

In the recent years, reliability study has made considerable use of data-driven BN techniques to create probabilistic graphical models that represent the causal relationship between various components of the system[72]–[75]. The BN uses graph theory to clearly explain problems' structure and reduce the complexity of probabilistic reasoning [76],[77]. Based on the Bayes theorem and the conditional independence assumption, the BN can also function as a classifier [76], [78]. B. Cai et al. (2020) [79]has used BN for predicting remaining useful life and fault occurrence of a system.

BN simulates the relationships between variables at a precise moment or over a predetermined period. BN does not explicitly model temporal links between variables, although a causal relationship represented by an arc implies such a relationship. BN models the relationship between a variable's current value and its past or future value only by including a new variable with a different name.

2.3.4 Dynamic Bayesian Network

A DBN is a derivative of the conventional static BN, and it is suitable for time series modeling since it is capable of capturing the temporal relationships among nodes[80]. DBN are a well-known addition to regular BN that enables precise modelling of changes over a time-slice. Intra-slice arcs show the relationships between the variables in a time-slice. Additionally, inter-slice arcs are used to visualise the interactions between variables throughout the time period [20]. DBN describes cause-and-effect relationships by probability distributions [81], [82]. BN and DBN-based reliability analysis in various applications is presented in Table 2.2.

Table 2. 2 Reliability analysis across industries using BN and DBN

Sl. No.	Application domain	Description	Author
1.	Software reliability	A BN model was used and compared to a Markov model to estimate the reliability.	Weber et al., 2012[72]
2.	Oil Industry	Two-layer BN model was used for analysing human reliability in process industries like an oil tanker	Ramos & Maturana, 2013[83]
3.	Process industries	A fuzzy BN approach improved the quantification of organisational influences in human reliability analysis.	P. cheng Li et al., 2012[84]
4.	Weigh-in-Motion system	A hybrid BN model constructs to complex data to estimate the reliability	Morales-Nápoles &

Sl. No.	Application domain	Description	Author
			Steenbergen, 2015[85]
5.	Electrical machine	A BN model was used for estimating reliability of grid service in electrical industry.	Doguc & Ramirez-Marquez, 2009[86]
6.	Pulp and paper industries	BN model has been Developed to estimate the reliability of complex design and complex operation in process industries	Pourret et al.,
7.	Off-shore pipelines	Reliability analysis of off-shore pipeline using BN through the cost-benefit method.	Friis-Hansen and Hansen
8.	Nuclear Power Plant	Reliability and risk analysis of the nuclear plant steam boiler system using BN model and compare this with FTA.	S. Hamza & Hacene, 2019[87]
9.	Communiction systems	Reliability analysis of communication electronic system to distinguish the occurrence of failure and develop the BN model with the help of RBD including the general gates.	. Kim, 2011[88]
10.	Offshore wind turbine	The hierarchical BN model is used to estimate the reliability of wind turbine support structure.	H. Li & Guedes Soares, 2022)[89]
11.	Software reliability	Estimating the reliability through the dynamic discretization of time to failure data.	D. Marquez et al., 2010[90]
12.	Water distributed system	Develop a chain like BN structure whose magnitude order is more efficient and reduce the computation time to estimate the reliability.	Bensi et al., 2013[91]
13.	CNC machine	Estimating the reliability of servo-feeding control of CNC considering the multi-state failure with a common cause and evidential networks.	Mi et al., 2018[92]
14.	Communication station system	Using the warm spare gates to analyse the system reliability through discrete BN method including multi-state condition.	X. Li et al., 2021[93]
15.	High-speed EMU	Bayesian network-K2 algorithm-expectation maximisation approach has been used for operational failure analysis.	Huang et al., 2021[94]
16.	Subsea blowout preventer	Modelling the reliability of subsea blowout preventers including the common cause and imperfect coverage using the DBN model.	Z. Liu et al., 2015[95]
17.	Chemical Plant	Predict the functional reliability of a system using system functional indicators and condition indicators of components using the DBN and Hidden Markov model.	Rebello et al., 2018[96]

Sl. No.	Application domain	Description	Author
18.	Electronic system	Used the prior knowledge of system functioning and malfunctioning though DOOBN for reliability analysis of complex electronic system.	Weber & Jouffe, 2006[81]
19.	Oil and gas industry	The application of the DBN model for life extension of a real firewater pump system including the preventive maintenance, functional test policies and uncertainty.	Ramírez & Utne, 2015 Ramírez & Utne, 2015[97]
20.	Power Grid	Cascading effects are evaluated with the help of the DBN model	Codetta-Raiteri et al.,2012[98]
21.	Subsea BOP system	Performance evaluation of subsea BOP system using the DBN includes imperfect repair and maintenance.	B.Cail et al.,2013[99]
22.	Sefaty valve	DBN model is used in Complex manufacturing processes like safety valves to estimate the reliability and optimise the maintenance activities.	Weber & Jouffe, 2006[81]
23.	Subsea BOP system	Estimating the reliability of subsea BOP system translating the FT into DBN directly with considering imperfect repair.	Cai et al.2013[99]

2.4 Maintenance of systems

Maintenance can be known as events essential to hold the system and its subsystem in operating condition and retain production sustainability while reducing operational cost [58]. Maintenance costs may be classified as a direct costs and indirect costs. Direct cost includes maintenance expenses like repair and labour costs, while indirect cost can be the non-physical consequences due to the hold of the system. Maintenance costs may increase due to unplanned maintenance activities, and downtime management of the system may fail to keep it at a sustained level. Furthermore, due to high demand and increased production, the system's failure rate increases, consequently increasing maintenance cost. Thus, it is necessary to develop more effective maintenance plans to minimize impact of failures.

In recent decades, the operating cost of the systems has dramatically increased due to increase of maintenance cost. In 2000, various industries in USA alone spent around $1200 billion on maintenance [100]. Another study shows that inadequate maintenance policy burdened approximately one-third of maintenance cost of the industries[101]. Therefore, proper maintenance policies should define how and when to implement corrective and preventive activities for reducing the operating cost and long life of systems.

2.4.1 Classification of Maintenance

Maintenance is categorised according to the occurrence of failures: planned and unplanned maintenance. Planned maintenance can be divided into two parts: preventive maintenance and corrective maintenance(CM). Preventive maintenance can be done through the visual inspection, monitoring activities and statistical analysis of previous failures while corrective maintenance is carried out only when a failure takes place. Unplanned maintenance is carried out in emergency cases when an unexpected failure occurs. In unplanned maintenance, only repair work is carried out without exploring the causes of the system's failure modes. The unplanned maintenance usually suffers from lack of spare parts and unacceptable delay in the breakdown by management. Thus, unplanned maintenance should be avoided as much as possible with planned maintenance. Fig. 2.4 details different types of maintenance plans.

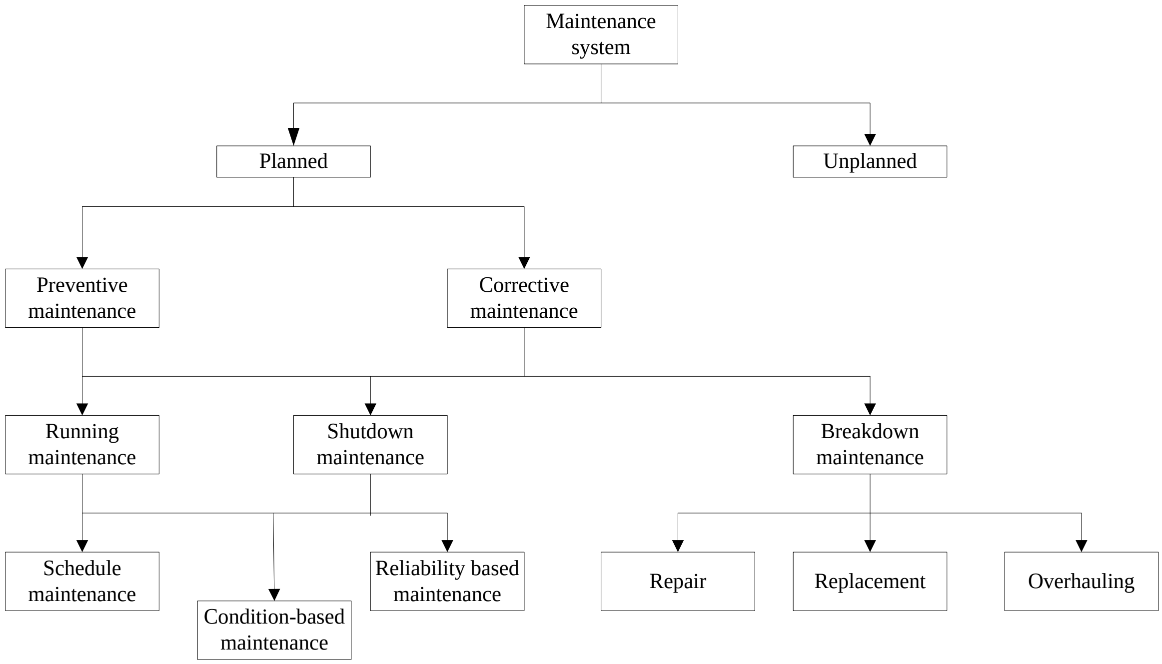

Figure 2. 1 Types of maintenance [102]

Preventive maintenance activities are done on right time or machine run schedule that help to detect the failure or degradation of a component or a system and help to increase the system's useful life by controlling the degradation at the accepted level. Preventive maintenance helps to decrease operating cost by 18% and saves the unwanted economic burden [103]. Preventative maintenance aims to avoid the potential failure of the system and resultant damage induced by ageing, wear and tear and structural incompatibilities. Thus, it is necessary to do the required inspection from time to time for enhancing the reliability and safety of the system and to prevent sudden failures.

In reliability engineering, failure indicates the systems or components that don't meet the required objective. To repair the systems, many maintenance policies have been proposed by researchers, as per shown in the figure 2.6. Failure of the systems comes under corrective maintenance policy, and along with repair, it is necessary to identify the failure modes. The acquired knowledge helps to prevent the future failure of the system or components. Table 2.3 shows the recent studies on preventive and corrective maintenance of systems.

Table 2. 3 Important studies on maintenance policies of various systems

Sr. No.	System	Studies	Authors
01.	Cooling Fan gear box	Corrective maintenance investigation using several characterisation techniques such as visual and metallographic examinations, hardness testing, and different chemical analyses	Meshari A.Al et al.2012[104]
02.	HVAC system	Maintenance investigation of hot water system using the availability based reliability centred maintenance scheduling.	Pourhosseini O., and Nasiri .,2018[105]
03.	Thermal Power plant	Optimising the maintenance schedule using the dimensional reduction method to maintain the higher availability	Zhang T., Nakamura M.,2002[106]
04.	Airline industries	Innovative condition-based maintenance scheduling has been developed by integrating complex data processing, feature extraction, prognostic algorithm, and maintenance scheduling optimisation	Li Z. et al.,2016[107]
05.	Automobile Production line	Holistic preventive maintenance schedule has been developed using the FMEA.	Alamri T.O. and Mo J.P.T., 2022[108]
06.	Wind Energy systems	Maintenance optimisation using cost optimisation of wind energy equipment like turbine	Shafiee M., Sorensen J.D., 2019[109]
07.	Electronic system	Preventive maintenance scheduling has been developed using IoT-based running time monitoring system (IRTMS) in PLC.	Sitompul E., Rohmat A.,2021[110]
08.	Aircraft systems	Maintenance optimisation of aircraft system has been developed using the reliability and maintenance cost.	Okara O.C. et al., 2016[111]
09.	Power Plant Machine	Developed the preventive maintenance model using FMEA to determine the machine damage analysis.	Islam S. S. et al., 2020[112]
10.	Computer hardware system	Preventive maintenance has been developed using continuous multi state system	Li R. and Zhang X., 2020[113]
11.	offshore wind farms	Hybrid interval maintenance has been developed based on periodic interval and opportunistic replacement.	Melo Y. R, et al.,2022[114]
12.	Bridge Structure	Predictive maintenance has been developed for multi-system-multi-components networks and optimisation through genetic algorithm	Liang Z. and Parlikad A.K., 2020[115]
13.	CNC Machine	Preventive maintenance investigation of CNC machine tool using monte-carlo simulation.	Qiu L.2014[116]

14.	Cellular manufacturing system	Preventive maintenance has been developed using minimising the maintenance costs and overall the probability of machine failures.	Das K. t al.2007[117]
15.	Process Industry	Optimal maintenance method has been developed using the imperfect inspection.	Kallen M.J. and Noortwijk J.M. van2006[118]
16.	Electrical network system	Particle Swarm Optimisation algorithm has been used for optimisation of preventive maintenance	Chalabi N. et al.,2015[119]
17.	Health equipment	Condition based maintenance (CBM) strategy has been developed for deteriorating equipment.	Alaswad S. , and Xiang Y.2012[120]
18.	offshore wind farms	Long term maintenance strategy has been developed including the high level uncertainty.	Li M. et al.,2022[121]
19.	Wind turbine	Developed the reliability based maintenance(RBM)t using FMEA and bond graph	Mo J. P. T. and Chan D. 2017[122]
20.	Automotive Industrial Equipment	Optimisation of CBM strategy of aging equipment using FMEA	Ramere, M. D., and Laseinde, O. T.,2021[123]
21.	Boiler turbine	Developed the maintenance strategy using the FMEA for preventive, predictive and corrective maintenance	Rahmania .S. et al.2020[124]

2.5 Reliability and maintenance works on mining machines

Heavy earth moving machinery (HEMM) is a backbone for mining industries to achieve the target production. Level of automation in industries is increasing to keep pace with the increasing production pressure. Thus highly reliable equipment is need of the day. Equipment reliability and maintenance are very important issues in mining industries. HEMM comprises various machinery like Dumper, rope shovels, Dragline, dozers, scrappers, drills, hydraulic excavators, wheel loaders, bull dozers, graders, and excavators, loaders, motor graders, trenchers, bull dozers, and backhoes etc. They do various types of activities like coal wining, drilling, overburden removal and material transportation in mining industries. In mining, managers mostly focus on achieving the production target, and there is not due attention on the equipment's reliability and maintenance, which also affects the production cost and reduces the overall profit of mining industries. Negligence in the maintenance of the equipment is a major concern in mining industry and the management do give much importance to it. Maintenance costs are major parts of the total operating costs of all production or manufacturing plants. Danielson(1987)[101] found that the maintenance cost in highly mechanised mine is around 40-60% of the total operating cost. The study of reliability and maintenance on HEMM equipment was not focused much until the 1990s. From early 90s, mining industries started talking on the performance and hence reliability and maintenance of HEMM.

In mining, it is necessary to identify and control the prominent failures and develop preventive or predictive maintenance policies for better availability of the equipment. Draglines are the massive earthmovers in an open cast mining project, and the production rate is highly sensitive about the breakdown of the dragline operation in open cast mining projects. There is dearth of research on the performance analysis of mining equipment like reliability analysis and maintenance policies optimization.

2.5.1 Performance studies of dragline

In Opencast mining, dragline is one of the important HEMM, which is used to strip the overburden. Deployment of dragline in open cast mining projects is very important to control the overall production cost of coal. In 1960, a walking dragline was commissioned at kurashia in South Eastern coalfields Ltd, Korba, India [125]. As of 2020, 43 draglines are deployed in different coal mines in Indian mines, including23 draglines working in different projects of Northern Coalfield limited(NCL), India [126]. Research works on draglines are conducted to improve the performance of dragline either by reducing the occurrence of unwanted failure, or by using reliability-centered maintenance policy to optimize the preventive maintenance interval of dragline components [7], [9], [127]. Studies also emphasized on lifetime parameter and failure mechanism [11], age-replacement model [5], or risk of failure components [9] of the dragline. The time counter algorithm is also used to optimize the inspection interval of the dragline components [6], [10]. For diagnosing faults, the expert system was developed considering important components of a dragline [128]. Table 2.4 shows the important work on the reliability and maintenance analysis of mining equipment including dragline. These works primarily follow the popular techniques of performance analysis. However the recent advancement of BN and DBN on the reliability and maintenance analysis has hardly been tried for dragline system.

Table 2. 4 Various methods of Reliability and maintenance used on the draglines

Sr.No.	System	Studies	Authors
01.	LHD	Statistical modelling has been used for the reliability and maintenance analysis of LHD.	U.Kumar,1990[42]
02.	Crushing Plant	Using the Statistical modelling for the reliability and maintenance analysis of crushing plant	Barabady & Kumar2008[12]
03.	LHD	Failure and repair data has been used for reliability and availability of LHD using the statistical model.	Samanta et al.,2004[60]
04.	Dump truck	Drum truck's reliabiity analysis also analysed by statistial modelling.	Allahkarami et al.,(2016)[129]
05.	Drilling machine	Markov model was used for reliability analysis of drilling machine in open cast mining project.	Javad Rahimdel et al.,2013[41]
06.	Dumper system	Kaplan-mier estimation is one of non-parametric method has been used for reliability analysis of dumper system.	Chanda Mauli et al.,(2014)[130]
07.	Belt conveyer system	Fuzzy fault tree has been developed for reliability and maintenance analysis of belt-conveyer system.	Gupta & Bhattacharya, 2007[21]
08.	Horizontal drilling machine	Monte carlo method with statistical modelling usinf for the reliability of horizontal drilling machine.	Soleimani et al(2014)[131]
09.	Bucket excavator dragline machine	RBD method is used for the Reliability & maintainability estimation of the ragline machine	Mohammadi et al.,2016[7]

10.	Mine hoist	Genetic algorithm method has been used for reliability and maitenance of mining hoist machine.	Vagenas N. & Peng S.(2001)[132]
11.	Dragline	Machine learning method KNN technique was used to prediction the failure of the dragline components	Taghizadeh & Demirel,2017[14]
12.	LHD	Support vector method(SVM) has been used for the reliability analysis. Also monte carlo method was used for data.	Dindarloo S. R.,(2014) [133]
13.	Hydraulic shovel system	FTA has been used for the reliability analysis and fault analysis of shovel system.	Samanta et al(2002)[134]
14.	Dragline	Statisitcal modelling has been done using the failure and repair data to analyised the reliability of dragline.	D. Kumar et al.,2020[8]
15.	Electric rope shovel	Estimated th reliability and maintnanblity of the four rope shovel system using repair and failure frequencies.	Roy et al.,2001[135]
16.	Crushing Plant	Estimated the reliability and availbility factors using survival and repair data and detected the critical sussystems.	Barabady & Kumar,2008[12]
17.	Dragline	Comparative study of reliability analysis of two draglines based on statistical model.	Uzgoren et al. 2010[136]
18.	Dragline	Using the non-homogenous Poisson process(NHPP) for esimating the reliability of dragline with lifetime trend.	Uzgoren & Elevli,2010[136]
19.	Dragline	Invetigated the components failure behaviour of two draglines using reliability importance factors and mean component availabilities.	Golbasi and Demirel,2013[137]
20.	Dragline	Using the monte carlo simulation for study of downtime profile of two draglines.	Golbasi and Demirel 2015[138]

2.6 Summary

The comprehensive literature survey on the reliability and maintenance methods used for solving various industrial problems and their uses in mining sectors are discussed in this chapter. The literature reviews mainly focused on the different reliability models and maintenance policies. In the literature, descriptive reliability and system reliability methods have been explained. Maintenance methods were also explained briefly. The BN and DBN model for inference-based reliability analysis has been highlighted.

The literature describes BN as one of the powerful tool for reliability analysis to explain the causal relationship between multi-layer problems. The BN-based reliability analysis also provides a good prediction accuracy, avoiding over fitting of data even with relatively small and incomplete sample sizes [139]. The BN model creates an 'expert system' including expert elicitation and is easily combined with decision analytic tools, and discrete and continuous monitoring data in the complicated system [139], [140]. DBN is a time series tool and gives the results in less computation time with more accuracy.