Chapter - 4

Data Collection & Preliminary Data Analysis

4.1 Data Acquisitions

This research has established, reliability and maintenance models using the operational data of a dragline, operating in a large surface coal mine. Data has been collected in the form of objective data, including the information on the daily reports and maintenance sheets about the dragline performance, maintenance, breakdown, failure occurrence time and repair duration over the period 2011 - 2015. While personnel beliefs of maintenance professionals on the details of maintenance activities at the mine site and their economic consequences were collected as secondary data.

Maintenance logbook recorded 1062 maintenance activities of the case study dragline during the data collection period. Collected data need to be prepared for analysis by cleaning the data, like removal of Human errors such as repeated records, tying errors and classifying failure data according to failure modes. On the other hand, subjective data was acquired via questionnaire surveys, participated by the dragline maintenance professionals. The questionnaire booklet contains great detail about the expected cost of corrective and preventive maintenance activities, the financial ramifications of production losses due to system halts, a list of tasks carried out during routine inspections, the specifics of the maintenance strategy currently being followed, and the structural and functional dependencies between components in the dragline.

4.2 Dragline System

The draglines are the most extensive mobile land equipment ever created and are generally built on-site for strip-mining operations to remove overburden and coal. It comprises a vast bucket suspended by wire ropes from a boom. Ropes and chains are used to manoeuvre the bucket. Electric motors power the hoist rope, and a drag rope is utilized for pulling the bucket assembly horizontally.

Manipulation of the hoist and drag ropes controls various bucket operations as desired. The dragline's bucket is filled by placing the bucket above the material to be dug and then lower and drag it across the material's surface. The bucket is then hoisted by the hoist rope and swung to the location where the material is to be deposited before the drag rope is released, causing the bucket to tilt and empty.

The dragline sits on the top of the overburden bench, usually 50 meters or so wide on the highwall side and excavates the material in front of itself to dump it on the strip's low wall or spoil side to uncover the coal seam. A dragline can easily dump the excavated overburden materials to a distance of around 100 m from the machine. A 6.6 kV supply line has powered the machine.

In this study, a 24/96 m^3 walking dragline 'X' (Figure 4.1) manufactured by Heavy Engineering Corporation Limited, commissioned in the year 1995, in a large surface coal mine in Northern India, was selected for the study. Failure data of the dragline 'X' over the period January 2011 to April 2015(52 months), were collected for the present analysis. The specific details of the studied dragline is outlined below:

Bucket capacity: 24m^3,

boom length: 96m,

weight of dragline: 2000 tonne,

boom angle: 30°,

operating radius: 88m,

drum diameter: 2.59m,

dump height: 39.6m,

hoist rope: 2×60mm(ϕ),

digging depth: 53.3m

drag drum diameter: 2.59m,

hoist drum diameter: 2×70mm,

base diameter: 15.25m,

shoe length: 17m,

shoe width: 2.8m,

walking speed: 0.24km/h,

maximum suspended area: 183m^3,

average ground bearing pressure: 0.95kg/cm^2.

Bucket specification: weight 32 tonne, capacity: 24m^3, width: 4.88m, number of teeth: 5 body material: alloy steel".

4.3 Data Collection

The operational data were collected from the daily report and maintenance logbook of the case study dragline system. Collected data are in raw format secondary type data and were recorded by the floor personnel for internal use [146]. Raw data have been prepared for statistical analysis by converting to EXCEL format, sorting and arranging in chronological order. Data have been classified to calculate Time to Failures (TTF) data of each subsystem and component of the dragline. Statistical analysis of ordered TTF data results estimated parameter(s) of the best fit distribution. Each subsystem comprises several components. Failure of a component affects the performance of the subsystem and hence the overall dragline system's performance. Component's failure frequencies have been calculated and shown through the pie chart given in figure 4.4 – 4.10.

4.4 Dragline subsystems and data classification

During operation, the dragline locate its buckets away from the main body of the dragline and strips overburden (OB) material by dragging the bucket towards the main body of the dragline. After stripping OB, the filled bucket is hoisted and swing to the de-coaled area for dumping the OB. Dragline's operating cycles consist of the following successive steps: excavating, hoisting, swinging and dumping actions in cycles.

For detailed reliability study, the dragline system is decomposed into a manageable number of subsystems considering operational and structural dependencies. The dragline has seven important subsystems like, bucket & accessories, dragging, rigging, hoisting, swinging, electrical auxiliary, and others. Figure 4.1 shows a schematic view of the case study dragline.

Figure 4. 1 A snapshot of the case study dragline operation

After identification of the components of each subsystem, failure of the components that caused breakdown of the dragline were allocated to the relevant subsystems. It is observed that assessments did not include some components with no history of failure during the study period. Table 4.1 presents a list of failure prone components of the seven subsystems.

Table 4. 1 Subsystems and important components of the dragline

Subsystems	Code	Components
Bucket &Accessories	S1	Bucket Teeth, Adapter, Equiliser pin, Anchor pins, Hitch Shackle
Dragging subsystem	S2	Drag rope, Drag socket, Drag pulley, Drag motor, Control system, Gearbox, Drag chain, Drag Brake, Drag Drum
Ragging	S3	Dump rope, Dump socket, Dump pulley
Hoist	S4	Hoist rope, Hoist chain, Hoist motor, Control system, Hoist Brake
Swinging subsystem	S5	Rotate Frame, Roller, gearbox, control system, Swing Motor
Electrical subsystem	S6	Exciter, M.G. Set, Synchronous Motor, DC Problem, Trailing Cable, Power failure
Others	S7	Compressor, Lubrication system, Guide Pulley, boom Light

Following the configuration of subsystems and their constituent parts, related failures are assigned to the subsystems. Figure 4.2 displays the failure frequency of each subsystem.. Total numbers of failures for 4 years period is 1062 for dragline. Total repair time is 4869.5 hours over the study period of four years. Swinging subsystem and dragging subsystem contribute 27% and 25% of total repair time respectively (Figure 4.3).

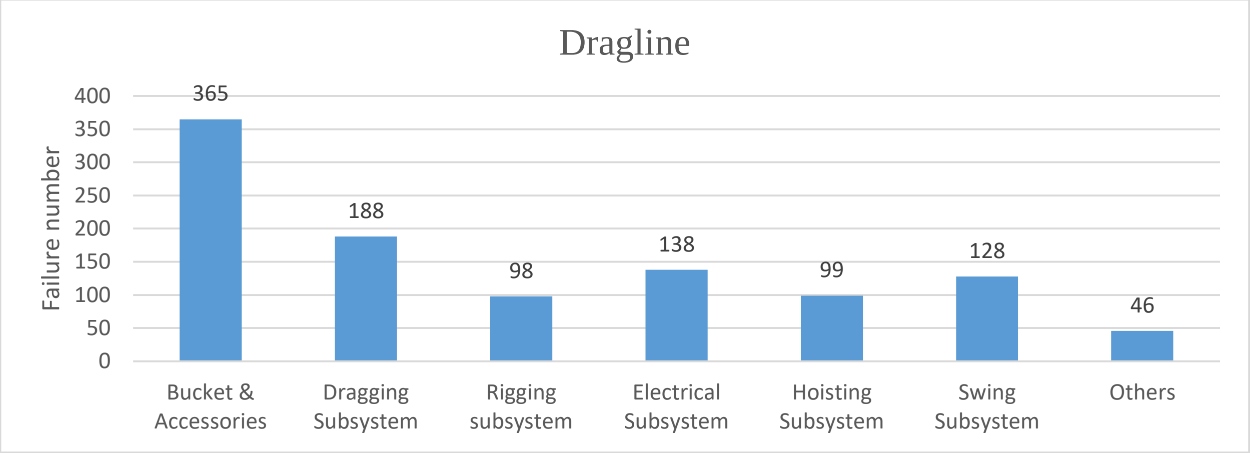


Figure 4. 2 Failure Number distribution for the Dragline

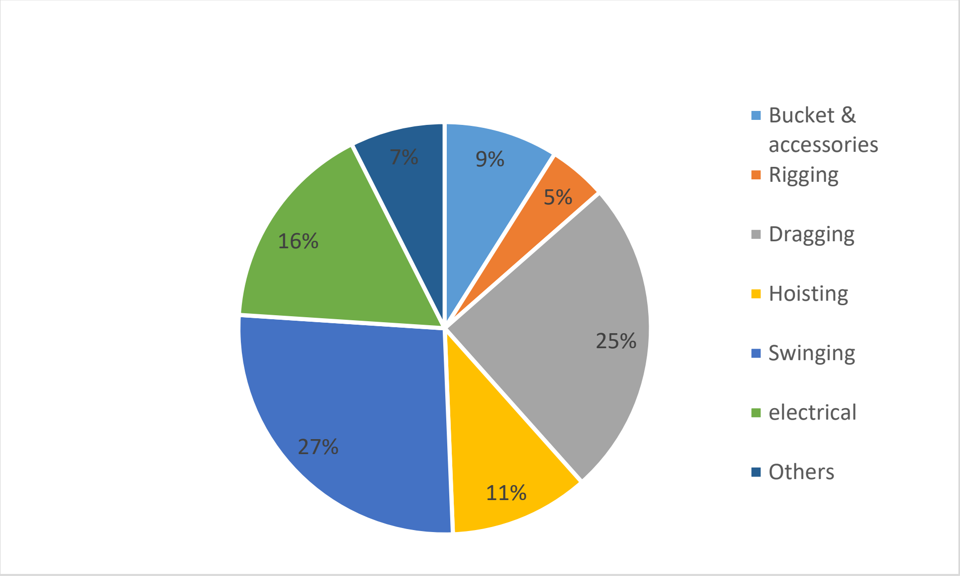


Figure 4. 3 Share of subsystems to the repair time of the dragline

4.3.1 Bucket & Accessories

‘Bucket & Accessories’ consists of components mainly: the bucket teeth, bucket structure, anchor pins, and hitch shackle pins. The bucket is one of the main component of a dragline and one of the most important components in the bucket and accessories subsystem. It is a steel alloy-made mechanical structure which dig the overburden with the help of bucket teeth. The bucket structure carries overburden. Digging of overburden causes wear and tear of bucket teeth, resulting in high failure frequency of teeth. Besides bucket teeth failure, various pin failure due to load stress has been observed significantly. The total number of failures in the ‘Bucket & Accessories’ subsystem along with all its associated components, has been noted to be 364 during the study period. The share of different components to the failure frequency of the ‘Bucket & Accessories’ is shown in Figure 4.4 by a pie chart.

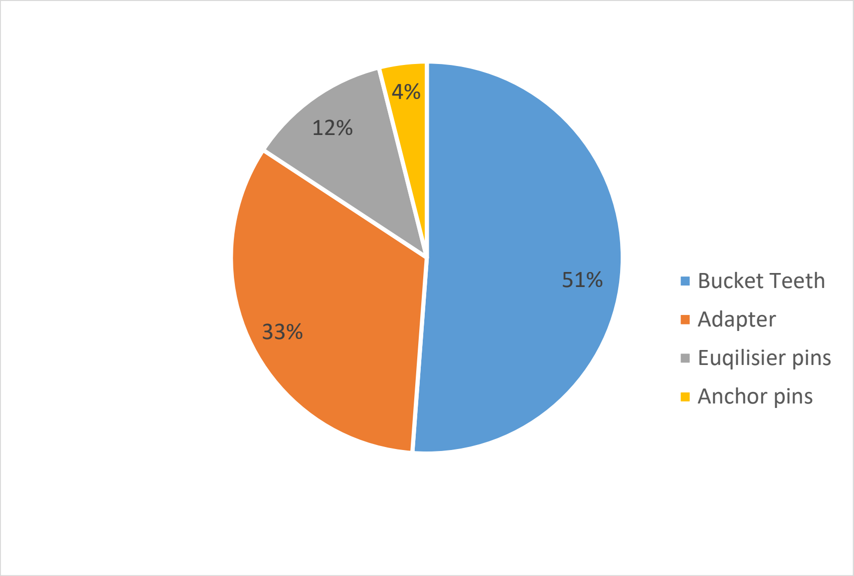


Figure 4. 4 Failure frequency of different components of bucket & accessories

4.4.2 Dragging mechanism

The ‘Dragging Mechanism’ integrates a drag rope, the drag socket, the pulley, the drag chain, the drag drum and the drag motor. The drag motor is attached to the gearbox assembly, brake and the control system. Drag motor helps to wind the drag rope on the drum. Figure 4.5 shows the failure frequencies of all the components, where the drag chain and the drag motor failure frequency are 25% and 15% respectively.

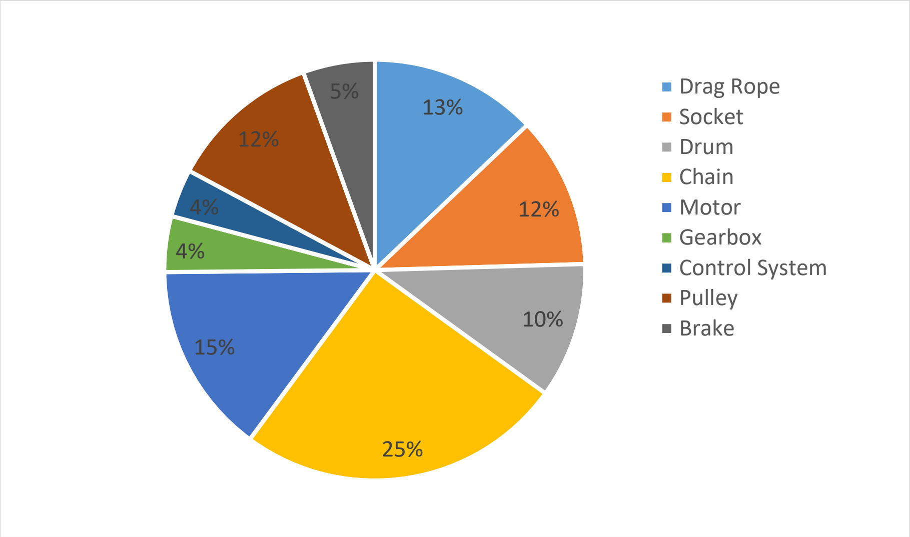


Figure 4. 5 Failure frequency of different components of dragging mechanism

4.4.3 Rigging Mechanism

The ‘Rigging Mechanism’ consists of the dump rope, the dump socket and the dump pulley. The dump rope is utilized to turn the bucket face from upward to downward direction which helps to dump the overburden in a specified area. The dump rope fails due to the wear with the dump pulley and the stress load. The dump pulley also fails due to frictional wear with the rope. Figure 4.6 shows the failure frequency of the dump rope. As it can be noted from figure 4.6, 65% of the failure frequency belongs to dump rope. Whereas the respective failure frequencies of the dump socket and the dump pulley are 27% and 8% respectively.

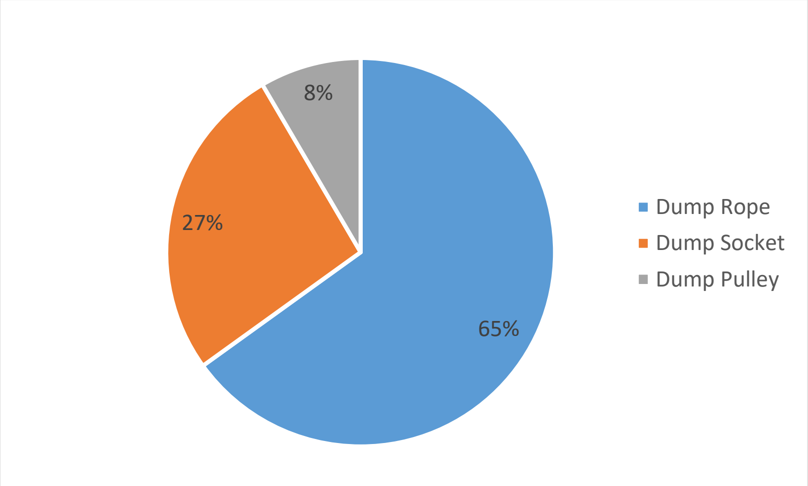


Figure 4. 6 Failure frequency of different components of rigging mechanism

4.4.4 Hoisting Mechanism

It consists of the hoist rope, the hoist chain, the hoist motor, and the brake. The bucket assembly is attached to the hoist rope, and the hoist rope travels in the vertical direction. 31% of the failure frequency is attributed to the hoist chain, when 27% of the failures is due to the hoist motor failure. The component-wise contribution to the hoist mechanism failure is listed in figure 4.7.

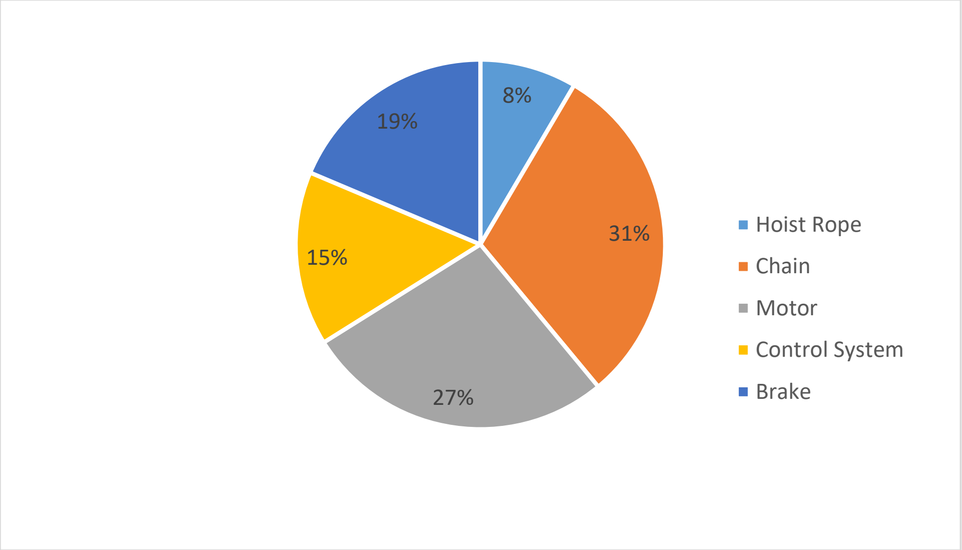


Figure 4. 7 Failure frequency of different components of Hoist mechanism

4.4.5 Swing Mechanism

This mechanism consists of the swing motor, the roller, the rotate frame and the gearbox attached to the motor. The entire dragline structure is mounted on this swing roller. Thus, displacement of the overburden with boom happens due to the roller and rotating frame. The failure frequencies of the components are shown in figure 4.8. Rotate frame is the highest failure contributor (28%) in 'Swing Mechanism'.

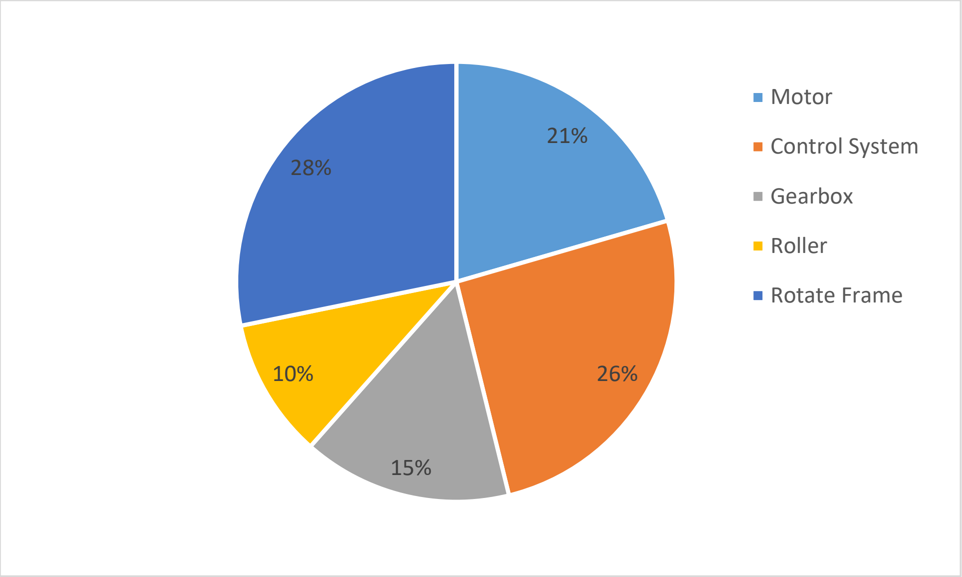


Figure 4. 8 Failure frequency of different components of Swing mechanism

4.4.6 Electrical Auxiliary

All the electrical components such as MG-set, the exciter, the synchronous motor, the power supply connector, DC converter, and the trailing cable failure are included in this subsystem. The failure frequencies of the components of this subsystem are presented in figure 4.9 in a pie chart. It can be seen from figure 4.9 that the MG-set failure frequency is around 55% of the total failures of the 'Electrical Auxiliaries'. Whereas, 16% of failures are attributed to the trailing cable.

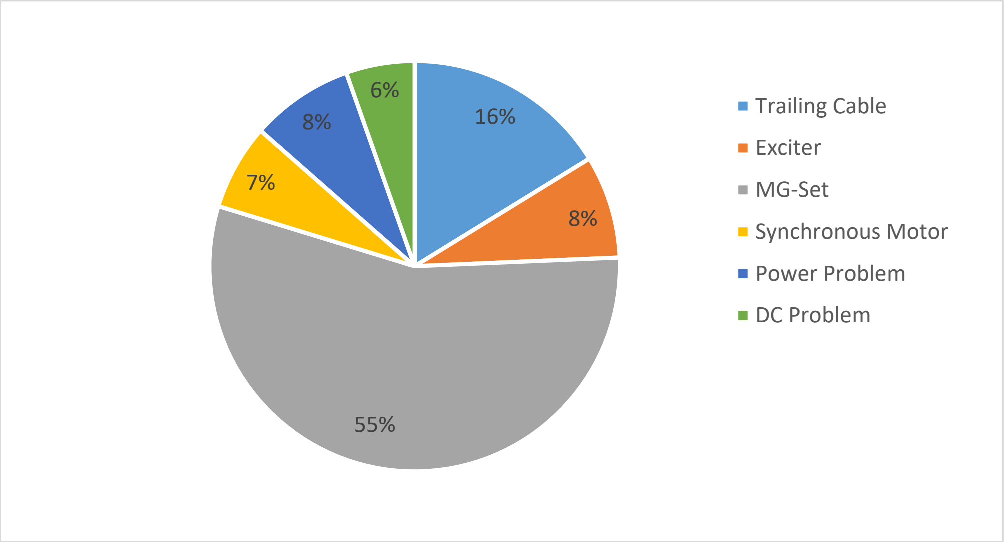


Figure 4. 9 Failure frequency of different components of electrical auxiliary

4.4.7 Others

Besides failures of the components mentioned above, failures do occur in the compressor, the lubrication system, the guide pulley, and the boom light. Failure of these components has low effects on the overall failure of the dragline. Figure 4.10 shows the failure frequencies of these components. The failure of lubrication system is a significant contributor, with a failure frequency of 50%.

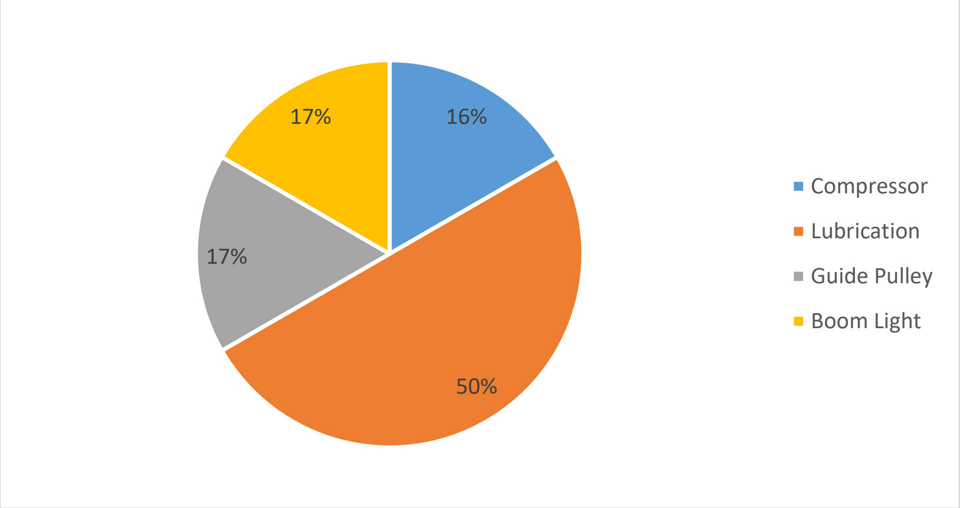


Figure 4. 10 Failure frequency of different components of others

4.5 Cleaning and preparation of collected field data

The quality and convenience of the prepared data may be directly influence the accuracy and validity of reliability and maintenance models. Missing values and errors in a dataset cause analysis outputs to deviate and provide unexpected results and conclusions. These anomalies might result from the effects of disregarding or skipping observation recordings, from using inconsistent data gathering techniques, or from mistakes made by humans when recording data. Various abnormalities and characteristics of data are identified using outlier, randomness, and trend tests as discussed below.

Outliers are data values or points that behave differently from the rest of the dataset. Outliers are extreme numbers that are surprisingly high or low and that are clearly outside the normal distribution of the data. These values must be identified and eliminated because outlier analysis causes findings to deviate negatively. As a graphical statistical tool, the boxplot, or box and whisker plot, may be used to understand the shape of the data distribution and identify extreme data values that may indicate the presence of outliers (Rossi, 2010). The first quartile (Q1), median (Q2), third quartile (Q3), maximum and lowest values of the sample, and number of observations are all five descriptive statistics used in a boxplot (Figure 4.11). The values denoting the 25th, 50th, and 75th percentile points in the distribution are, respectively, the first quartile, median and the third quartile.. Box plots are a nonparametric test and used with any kind of data.

Box plots were used in the study to identify outliers in the survival (TTF) and repair (TTR) data of the individual dragline components. An example figure for the dragline's Bucket & Accessories subsystem's components is shown in Figure 4.4.

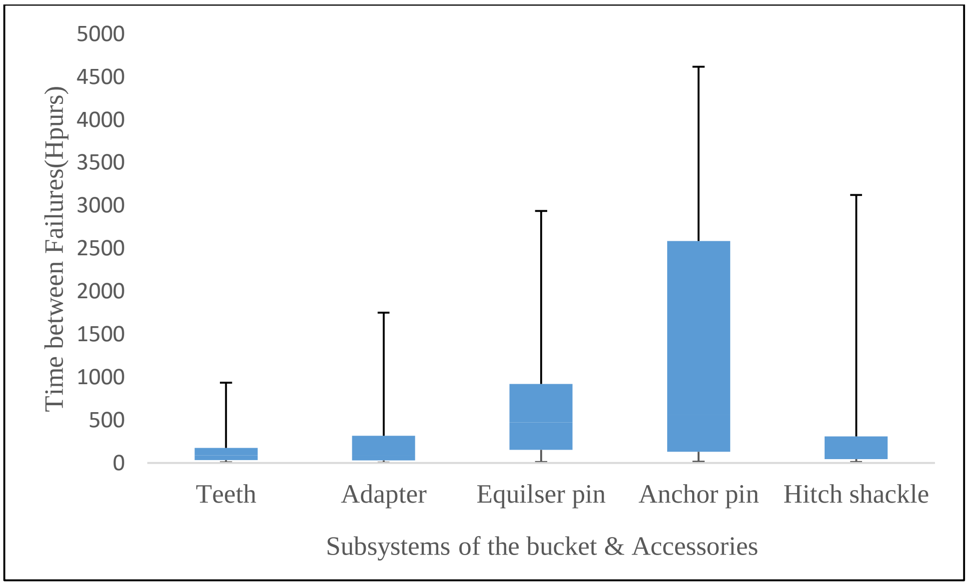


Figure 4. 11 Boxplot of the TTFs of components of Bucket & Accessories subsystem

The plots also show that component distributions are often right-tailed, which causes data to accumulate toward the origin and large values to be seen in the distributions.

4.5.1 Trend Analysis

Reliability studies can assume data trends, rather than data anomalies, as characteristics of lifetime behavior. Therefore, the issue of trends was explored in detail using hypothesis testing methods. In the reliability evaluation, it is necessary to verify whether repairable parts are in the life wear/improvement period. This condition has a great impact on how a component is evaluated for reliability.

4.5.1.1 Graphical Method

Lifetime data trends can be analyzed qualitatively and quantitatively. Qualitative graphs plot (i) Cumulative Number of Failures (CFN) vs. Cumulative Mean Time to Failures (CTTF), (i) Downtime vs. Cumulative Mean Time to repairs (CTTR), and (i) Downtime vs. Cumulative Mean Time to Failures can be created by (MTTF) is plotted on a logarithmic scale (called a Duane plot). Figure 4.12 shows a sample plot using these qualitative methods.

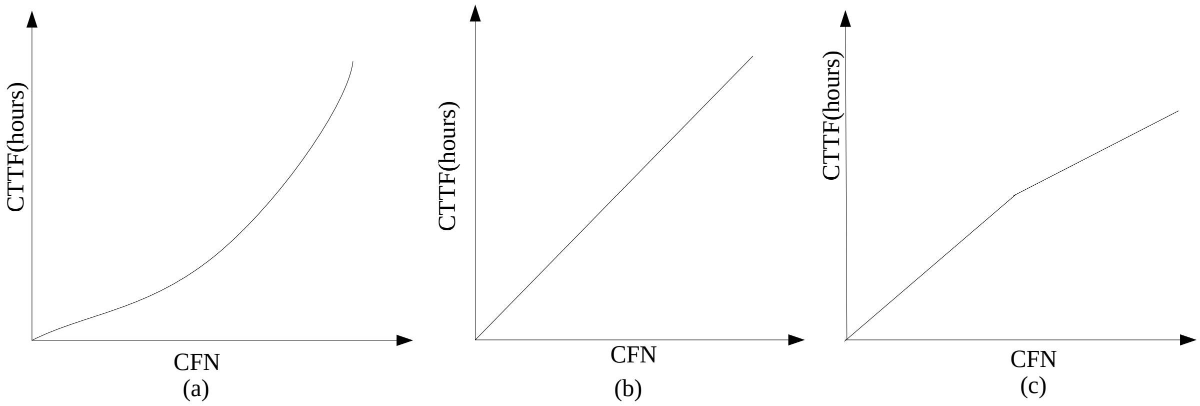


Figure 4.12 Sample plot of CFN versus CTTF

For the system under observation, Figure 4.12 shows typical 'cumulative failure number against cumulative time to failures' plots. Figure 4.12 (a) reflects the existence of pattern in the data set.. When a linear plot is produced, it may be considered that the data do not exhibit any trend, as illustrated in Figure 4.12(b). Sometimes two or more straight lines are shown rather than a single linear plot, as in Figure 4.12(c). This could be the outcome of adjustments made to the system's operating environment or the maintenance plan. When this happens, one option is to eliminate data that is not indicative of the current situation; as a result, the most recent data set would produce a no-trend plot, and an assumption about the renew process (RP) may then be formed.

This trend analysis technique is incredibly simple to use and doesn't involve any calculation. When there are significant trends in the data, this strategy is particularly effective. When there is a little trend in the data, this approach might not be sufficient, thus an analytical method should be employed to confirm the solution.

4.5.1.2 Analytical Method

The use of analytical methods can help to validate the findings of graphical approaches and to get more objective outcomes. In the examination of data trend for repairable systems, Crow/AMSAA, pair-wise comparison nonparametric test (PCNT), Laplace test, and Lewis-Robinson test are widely utilised (Wang and Coit, 2005). Leis-Robinson and PCNT techniques determine if the data are appropriate for an ordinary renewal process, whereas Crow/AMSAA and Laplace methods determine whether the data can be fitted in a homogeneous Poisson process or not. Remember that the data here follows an exponential distribution and that the homogeneous Poisson process (HPP) is a subset of the ordinary renewal process (ORP). A strong indicator of non-trend behaviour might be the validity of HPP or ORP in these tests.

4.6 Preliminary Data Analysis

Preliminary analysis of the failure data identifies its characteristics that help in further analysis of data. Detail reliability study of the dragline system entails the reliability modelling of components of each subsystem which is usually accomplished by estimating the parameters of the best fit theoretical distribution to the failure data of the component. The TTF data set of each component is fitted to the popular failure distributions, and the distribution parameters are estimated. A goodness of fit test identifies the best fit distribution for the TTF data set of each component. The entire process of preliminary data analysis is elucidated through a flowchart (Figure 4.13).

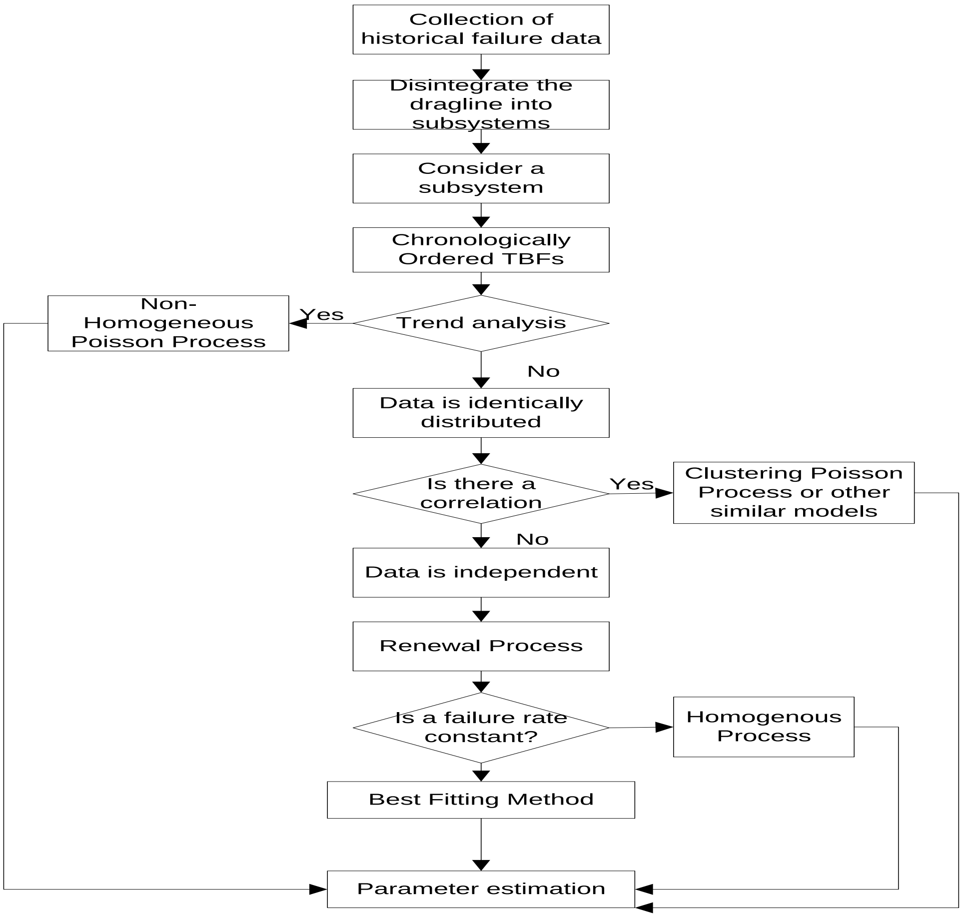


Figure 4.13 A flowchart of the methodology for preliminary data analysis[42]

4.6.1 Methodology

The following steps as given in fig. 4.13, have been followed for the analysis of failure data of the system/subsystems.

1. Data collection and cleaning: Data collection from field maintenance logbook records, and check for recording errors, incompleteness and any inconsistencies.
2. Classification of failure data: Component wise classification of failures, calculation of TTFs and outliers check.
3. Examination of IID of TTFs: Perform trend test, serial correlation test and determine by graphical/analytical methods.
4. Modelling of failures: Model the failures of components as a renewal process (RP), a

homogenous Poisson process (HPP), a non-homogeneous Poisson process (NHPP), or any other process and estimate the values of model parameters.

4.6.2 Identification of the best fit failure distribution and estimation of its parameters

For the time constant or time-dependent model, the statistical analysis of failure incorporates trend analysis, selecting the best-fit distribution, and calculating model parameters. Following the methodology detailed in section 4.5.1.1 and following the steps outlined in figure 4.13, TTFs have been analysed as detailed in the following section.

The trend and correlation study (figure 4.14) of the TTFs of each component have been carried out as given in figure (figure 4.14).

Using TTF data of components, the trend and correlation for failure data has been carried out which decides that data follows the theoretical distribution or Non-Homogeneous Poisson process (NHPP) methods (fig. 4.13). If trend test is a straight line then it implies that TTFs of the component follow the conventional parametric distribution process. This analysis helps to identify the components whose failure process can be modelled by the Non-Homogeneous Poisson process (NHPP) approach, i.e. when a visible trend is observed in the CTTF vs CFN plot. The trend and correlation study of the TTFs of each component have been carried out as given in figure (figure 4.14).

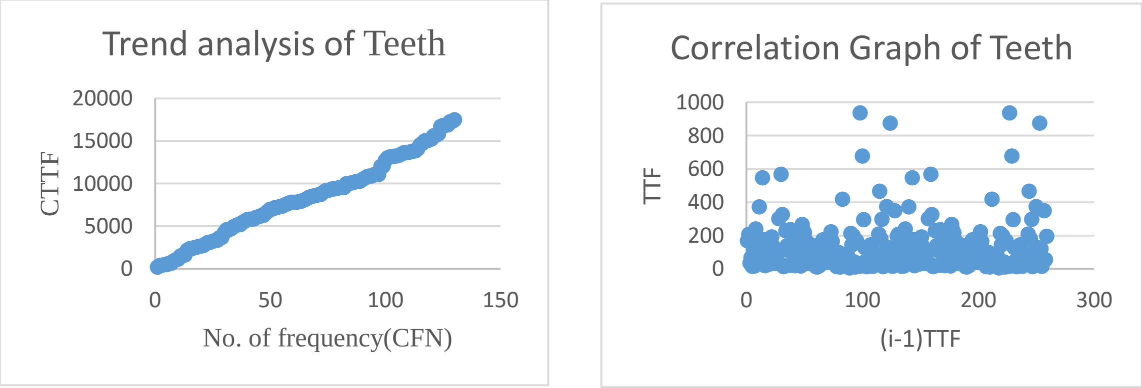


Figure 4.14 Trend and correlation graph of teeth

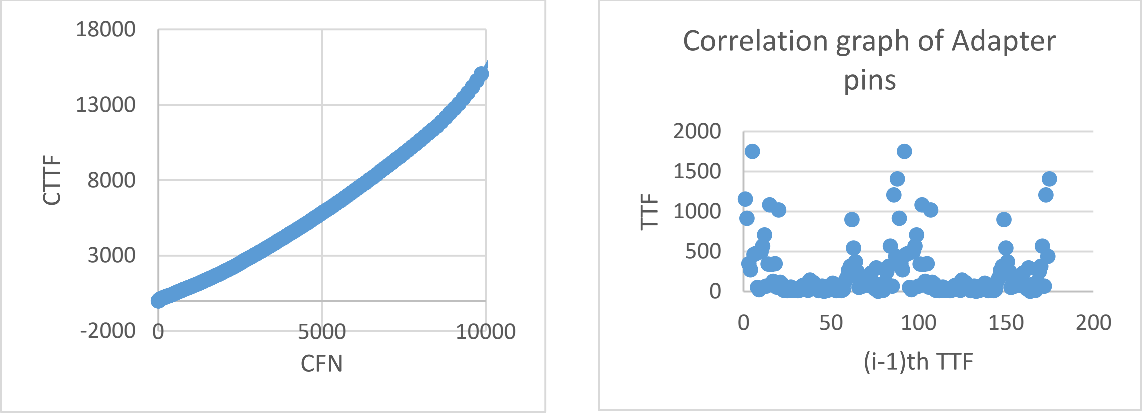


Figure 4.15 Trend and correlation graph of Adapter pin

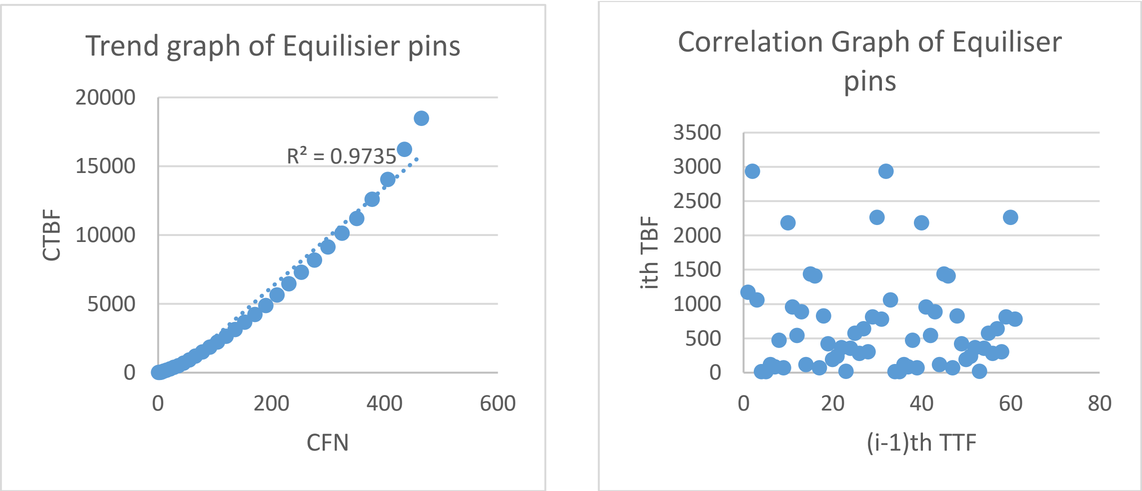


Figure 4.16 Trend and correlation graph of equiliser pins

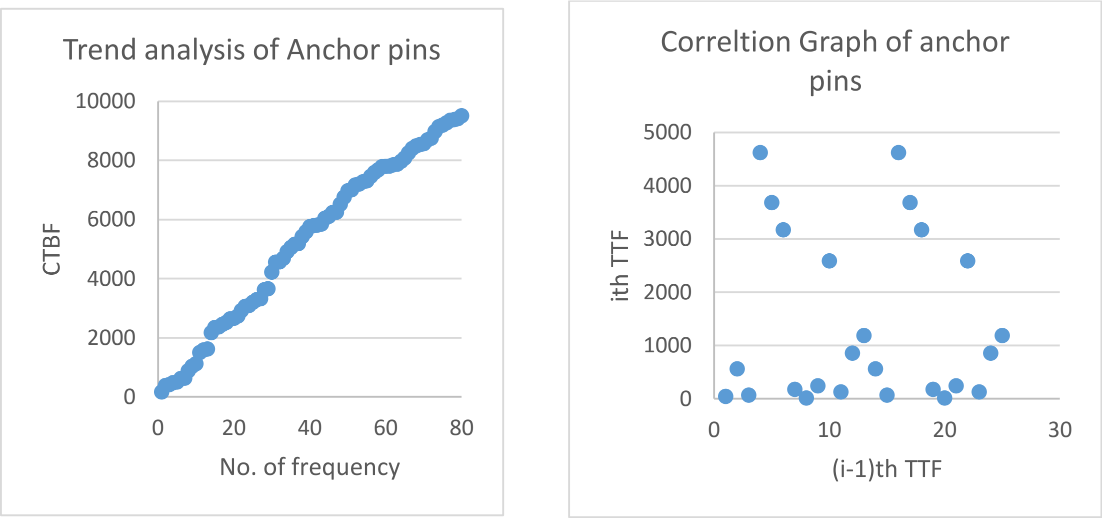


Figure 4.17 Trend and correlation graph of anchor pins

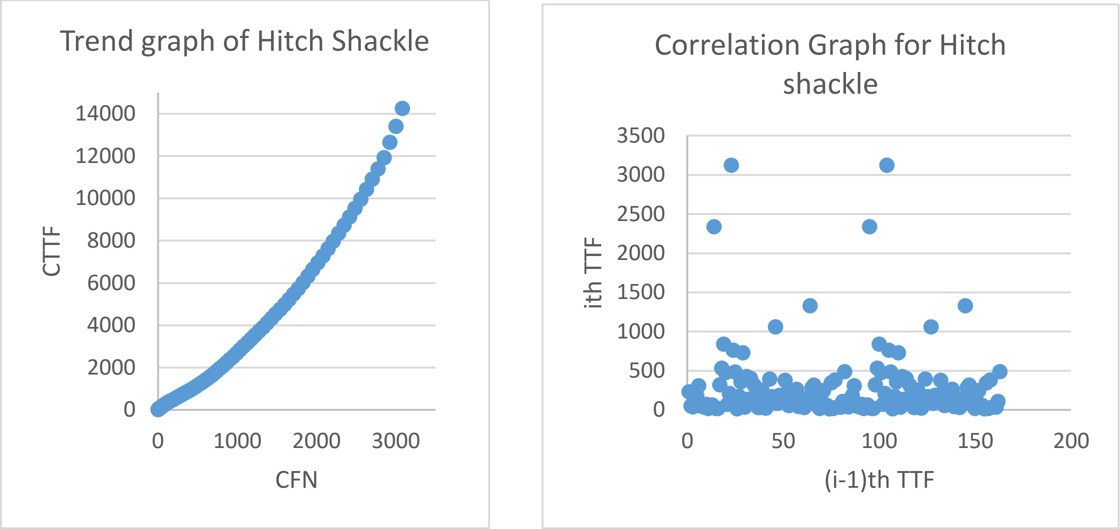


Figure 4.18 Trend and correlation graph of hitch shackle

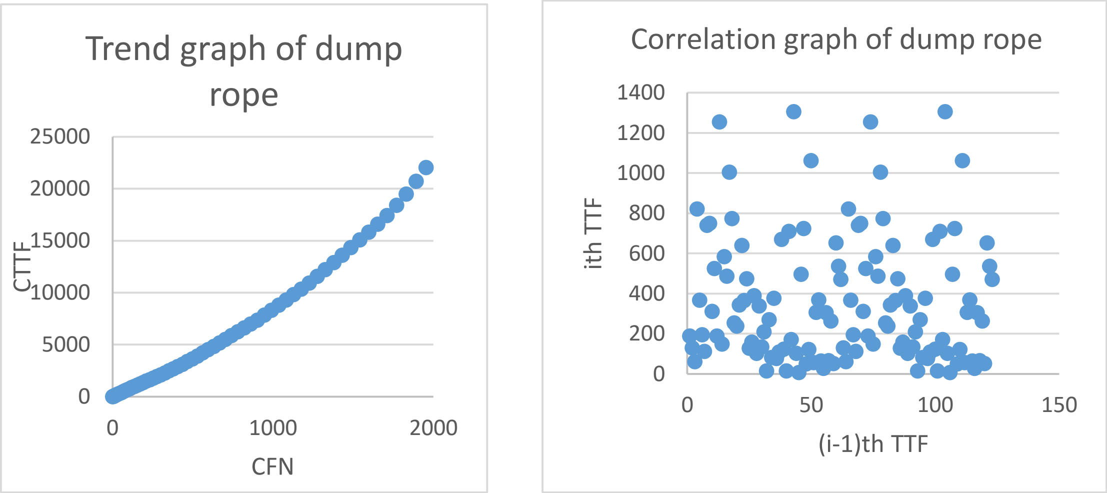


Figure 4.19 Trend and correlation graph of dump rope

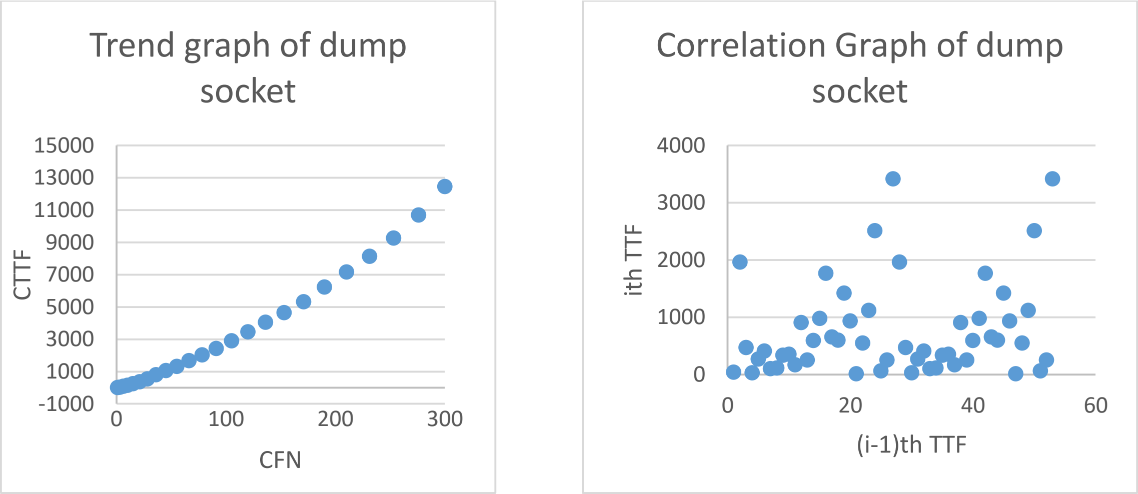


Figure 4.20 Trend and correlation graph of dump socket

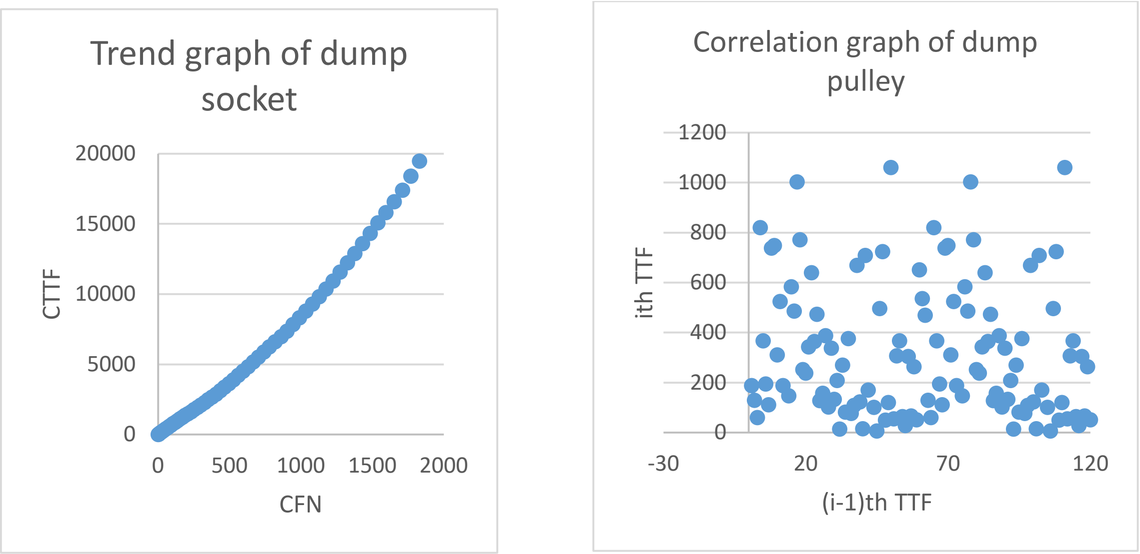


Figure 4.21 Trend and correlation graph of dump pulley

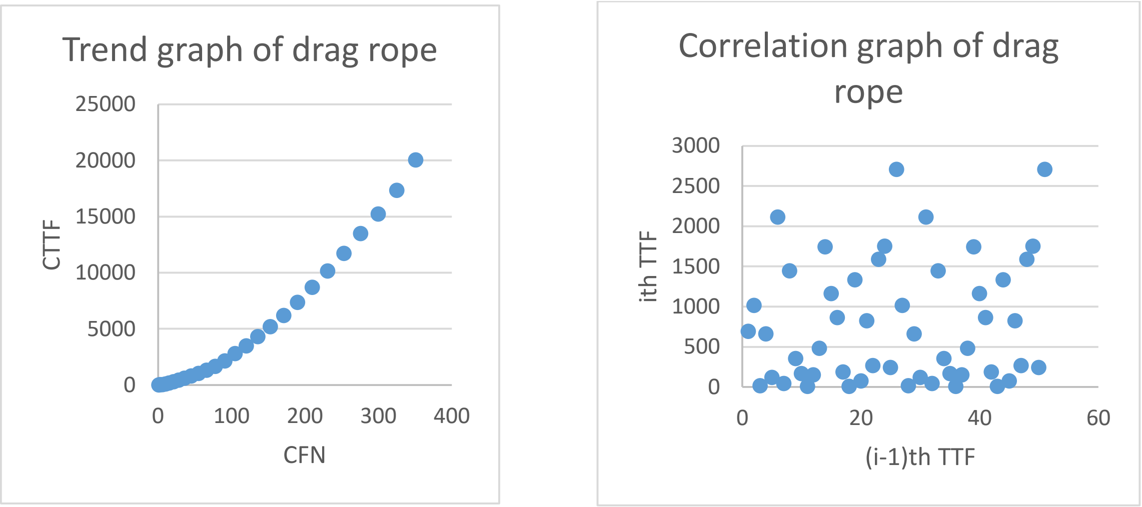


Figure 4.22 Trend and correlation graph of drag rope

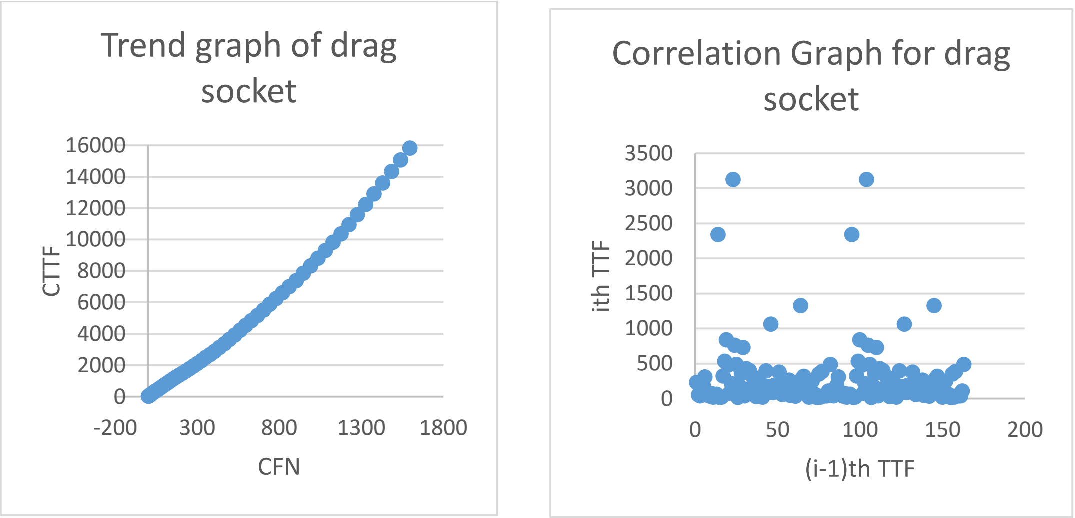
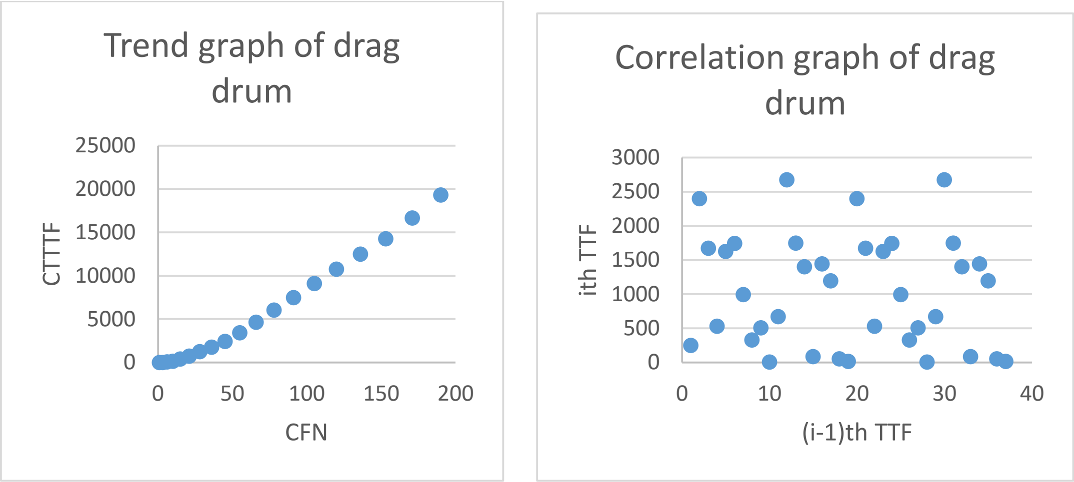
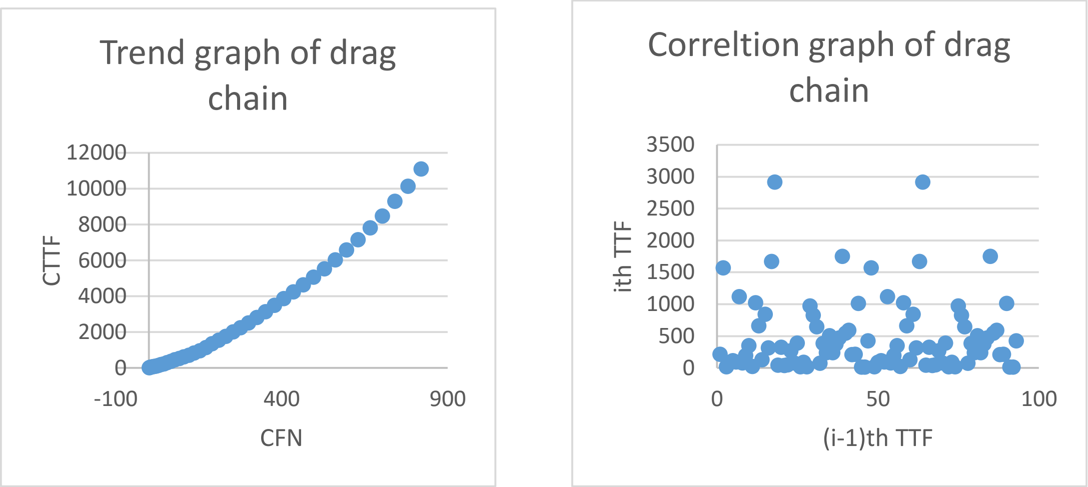


Figure 4.23 Trend and correlation graph of drag rope


Trend graph of drag drum

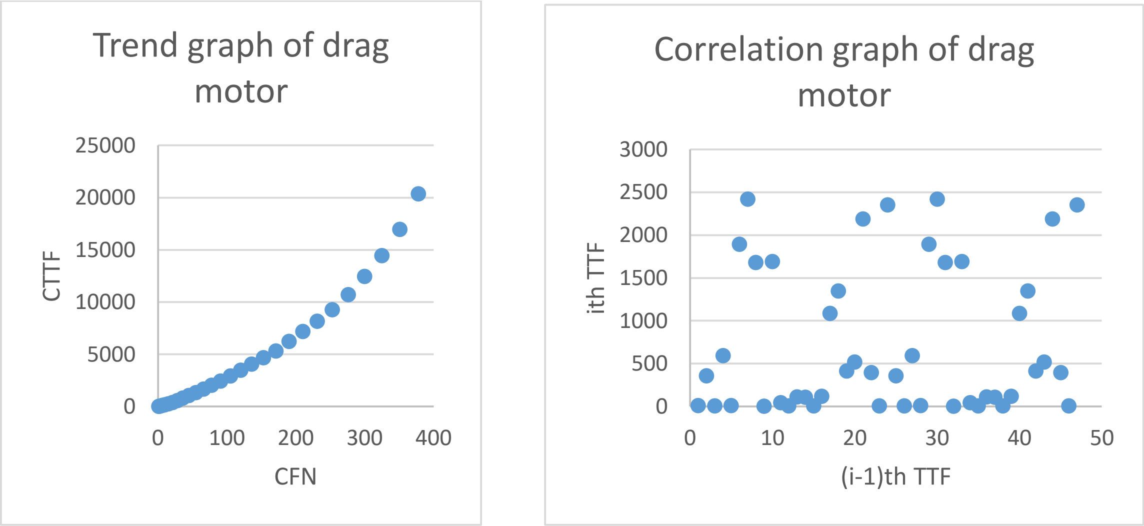
Correlation graph of drag drum

Figure 4.24 Trend and correlation graph of drag drum


Trend graph of drag chain

Correltion graph of drag chain

Figure 4.25 Trend and correlation graph of drag chain


Trend graph of drag motor

Correlation graph of drag motor

Figure 4.26 Trend and correlation graph of drag motor

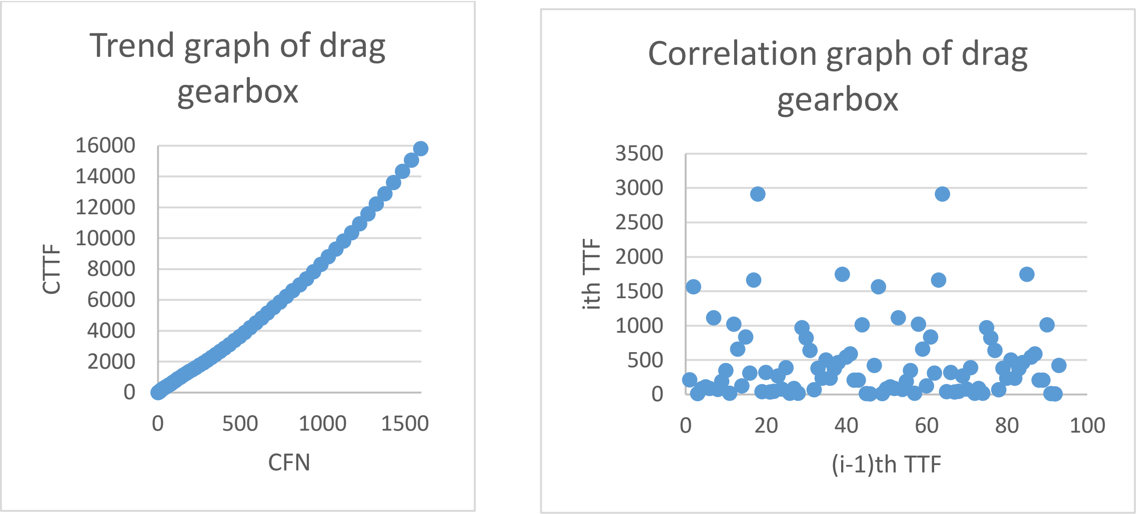


Figure 4.27 Trend and correlation graph of drag gearbox

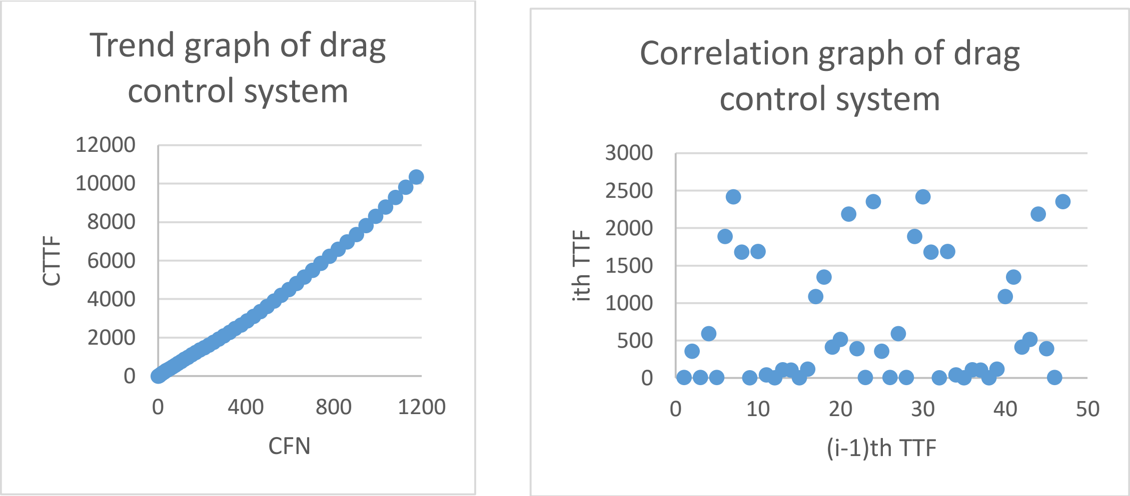


Figure 4.28 Trend and correlation graph of drag control system

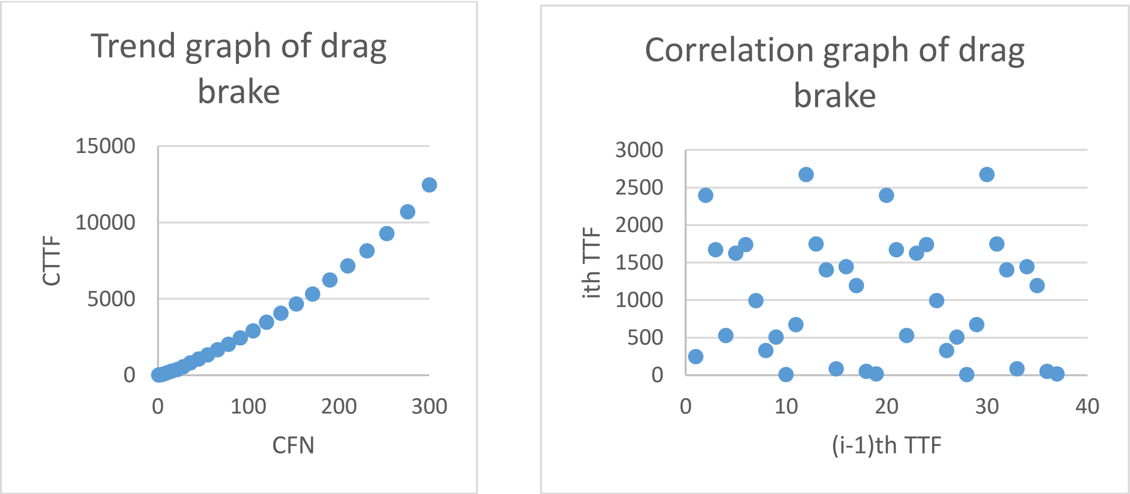


Figure 4.29 Trend and correlation graph of drag brake

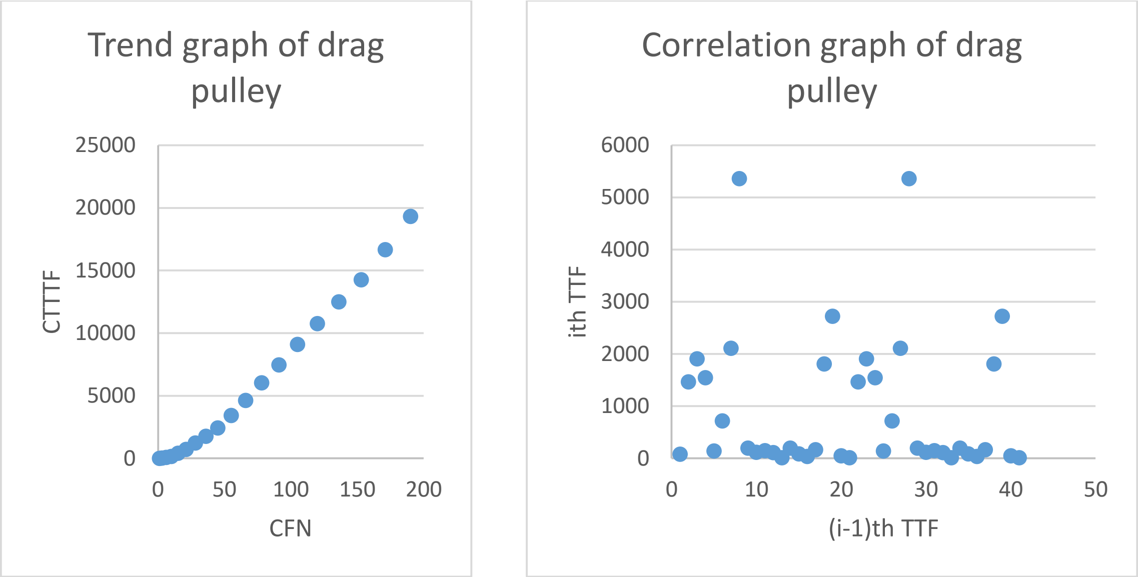


Figure 4.30 Trend and correlation graph of drag pulley

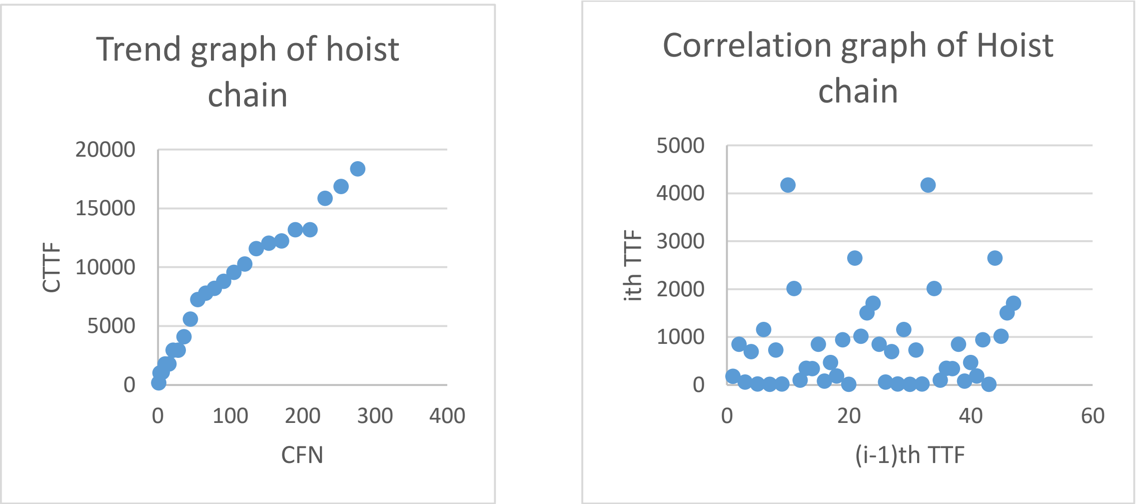


Figure 4.31 Trend and correlation graph of hoist chain

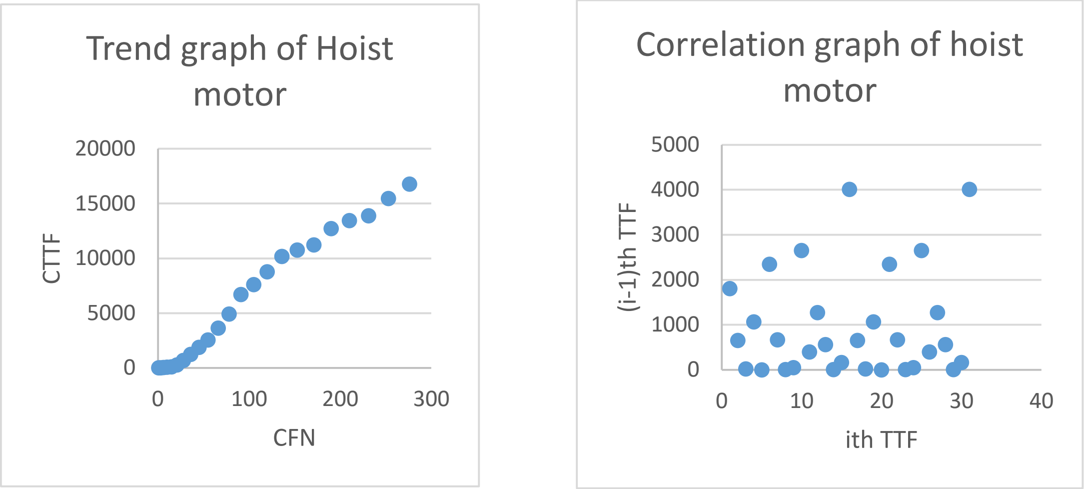


Figure 4.32 Trend and correlation graph of hoist motor

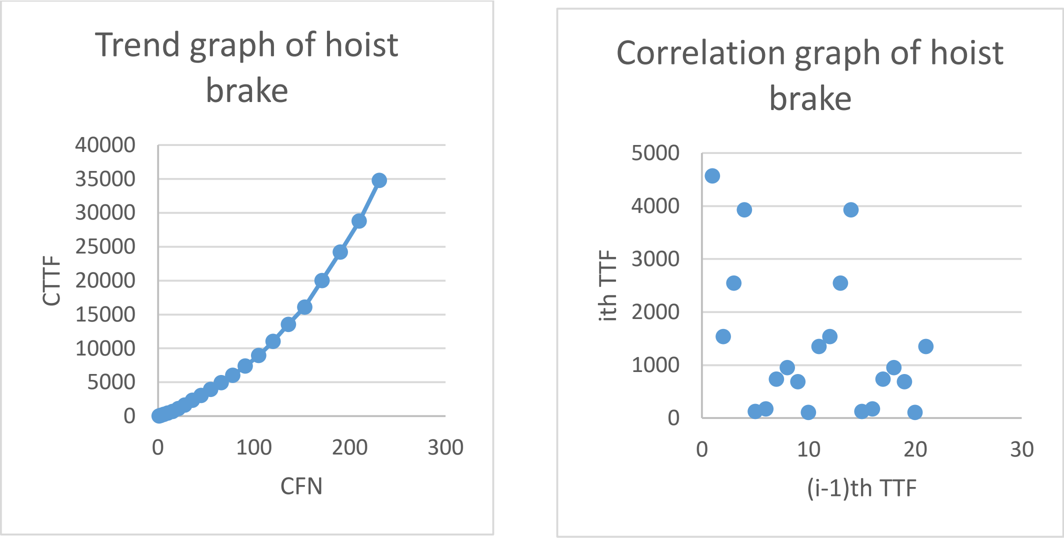


Figure 4.33 Trend and correlation graph of hoist brake

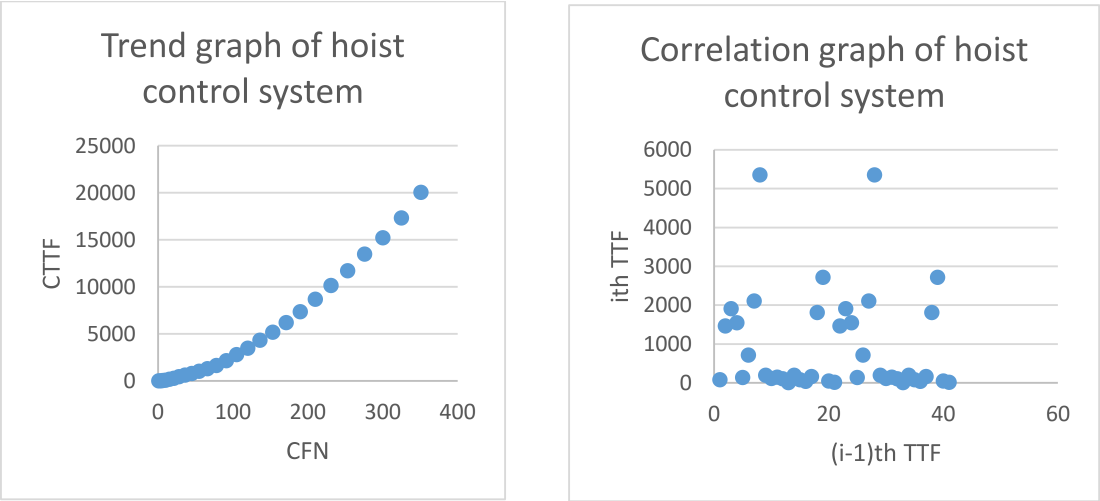


Figure 4.34 Trend and correlation graph of hoist control system

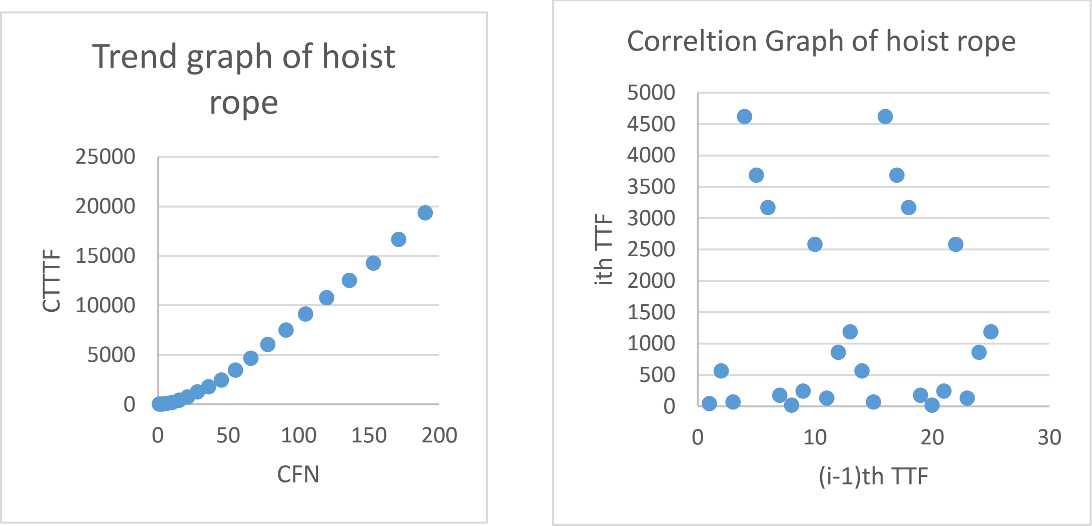


Figure 4.35 Trend and correlation graph of hoist rope

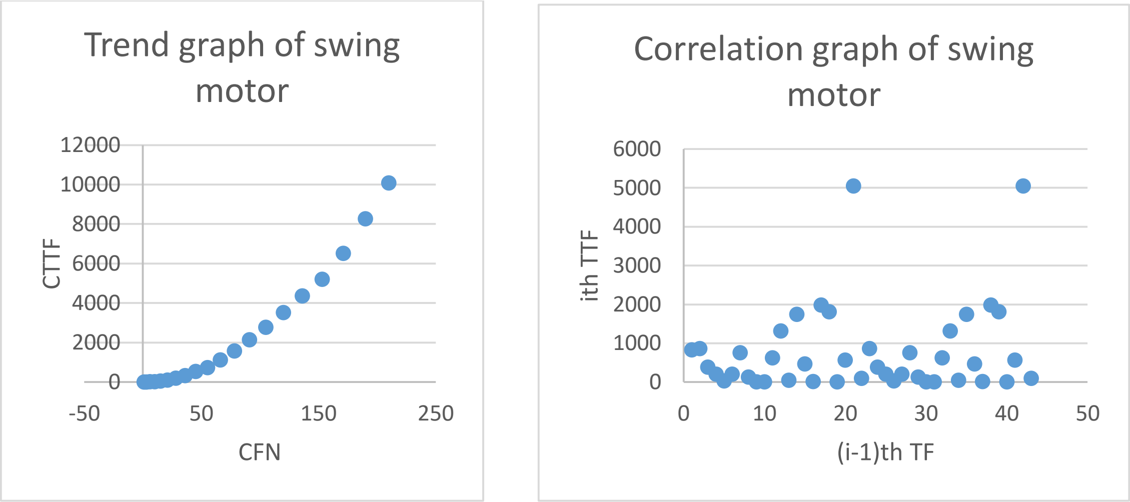


Figure 4.36 Trend and correlation graph of swing motor

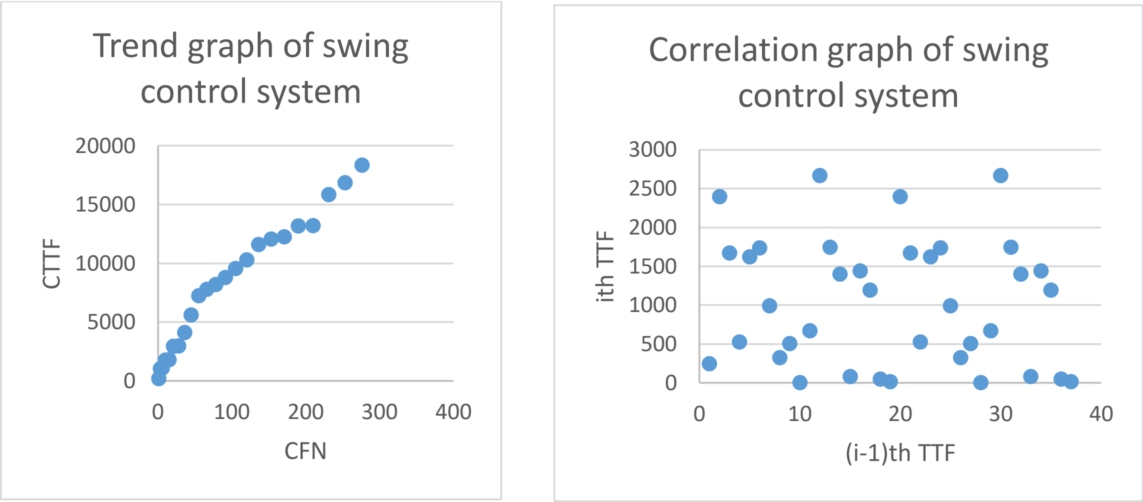


Figure 4.37 Trend and correlation graph of swing control system

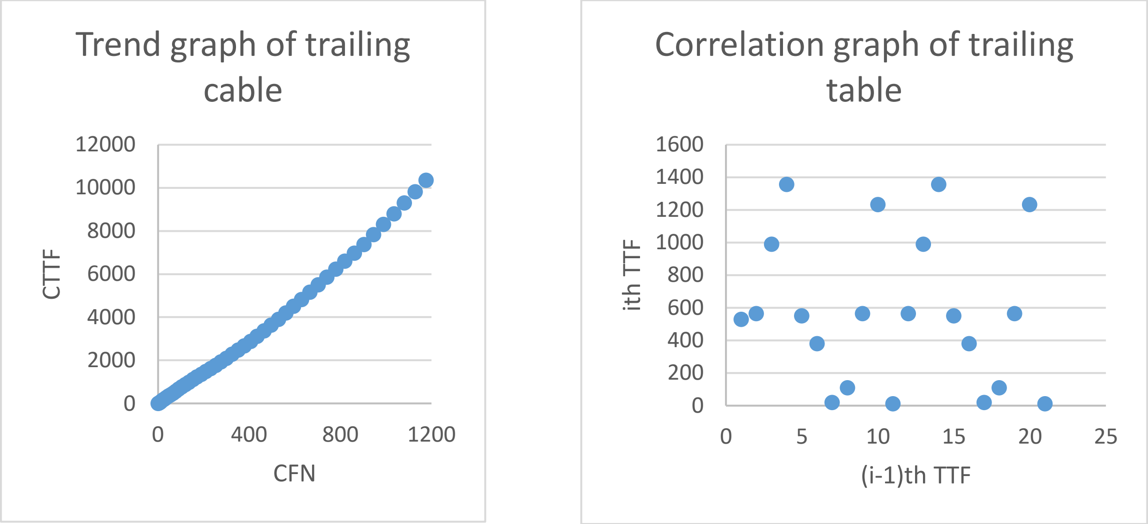


Figure 4.38 Trend and correlation graph of trailing cable

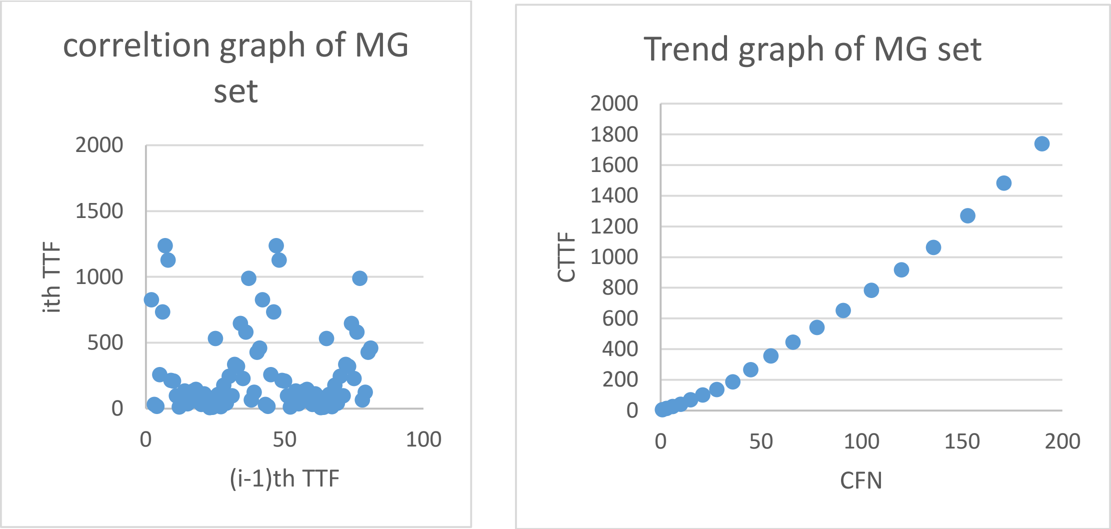


Figure 4.39 Trend and correlation graph of MG set

In this study, dragline is divided into seven major subsystems namely, Bucket & Accessories, Rigging, Dragging, Hoisting, Swinging subsystem, Electrical Auxiliary, and others. Each of these subsystems comprise of a group of components, some are important from failure aspect of the dragline (Table 4.2) and have different failures frequency.

The goodness of fit test for the important components of each subsystem of the dragline is performed (Table 4.2), and it is observed that the Weibull distribution is the best fit distribution for the collected failure data. The failure probability distribution for the Weibull distribution is defined as

$$f(t) = \frac{\beta}{\theta}\left(\frac{t}{\theta}\right)^{\beta-1} e^{-(t/\theta)^{\beta}} \tag{6}$$

Where f(t) is the failure probability distribution function

The Weibull distribution parameters (β, η) for different subsystems and components have appeared in Table 4.2

Table 4. 2 Result of statistical analysis of TTF data of various components of dragline

System/ Subsystems	Components		K-S test (Goodness of fit)			Best Fit distribution	Parameters
Bucket & Accessories(S1)	Bucket &Accessories		Exponential	Normal	Weibull	Weibull	
	Teeth Failure(X1)		0.06809	0.2019	0.06404	Weibull	Beta= 1.0053, Eta = 134.8345
	Adapter failure (X2)		0.21554	0.26198	0.105	Weibull	Beta = 0.7535, Eta = 178.0693
	Equaliser pins(X3)		0.1715	0.07208	0.10406	Weibull	Beta = 0.9523, Eta = 603.9111
	Anchor pins(X4)		0.29476	0.23159	0.14781	Weibull	Beta 0.7999868, 1348.2628097
	Hitch Shackle pins(X5)		0.15111	0.28913	0.08046	Weibull	Beta = 0.8485, Eta = 248.7853
Drag Mechanism(S2)	Drag motor system(SE1)	Drag Motor Failure(X6)	0.35906	0.25565	0.21017	Weibull	Beta = 0.5282, Eta = 381.0453
		Drag Motor Failure(X7)	0.35906	0.25565	0.21017	Weibull	Beta = 0.5273, Eta = 427.7129
		Control system Failure(X8)	0.23553	0.21079	0.20784	Weibull	Beta 1.0649 , Eta = 3199.7096
	Drag rope Failure(X9)		0.13125	0.17132	0.07231	Weibull	Beta = 0.8459, Eta = 751.4251
	Gearbox Failure(X10)		0.1635	0.21599	0.11151	Weibull	Beta = 0.7733, Eta = 2076.3137
	Drag Drum failure(X11)		0.16867	0.14295	0.11753	Weibull	Beta = 0.9205, Eta = 920.5721
	Drag Chain Failure(X12)		0.14519	0.21286	0.07541	Weibull	Beta 0.8558992, 433.3874504
	Drag Brake Failure(X13)		0.46177	0.39737	0.19888	Weibull	Beta = 0.5239, Eta = 866.9491
	Drag Socket Failure(X14)		0.28309	0.24276	0.14973	Weibull	Beta = 0.5766, Eta = 589.4482
	Drag Pulley Failure(X15)		0.42184	0.32111	0.23926	Weibull	Beta = 0.6272, Eta = 574.75445
Rigging Mechanism(S3)	Dump rope Failure(X16)		0.06553	0.13572	0.06366	Weibull	Beta = 1.103182, Eta = 364.8115
	Dump Socket Failure(X17)		0.08534	0.2134	0.06514	Weibull	Beta = 0.9650, Eta = 779.78103
	Dump Pulley Failure(X18)		0.21479	0.21174	0.22003	Weibull	Beta = 1.5986, Eta = 2594.3779
Hoisting Mechanism(S4)	Hoist motor	Hoist Motor1 failure(X19)	0.25897	0.2306	0.14323	Weibull	Beta = 0.60262, Eta = 708.9927

	system(SE2)	Hoist Motor2 failure(X20)	0.25897	0.2306	0.14323	Weibull	Beta = 0.60262, Eta = 708.9927
		Control system Failure(X21)	0.1472	0.23639	0.08791	Weibull	Beta = 0.8478, Eta = 1733.8110
	Hoist Rope Failure(X22)		0.1961	0.2302	0.17429	Weibull	Beta 0.6811, Eta = 2543.9350
	Hoist Chain failure(X23)		0.17892	0.20548	0.10658	Weibull	Beta 0.7459, Eta = 775.8248
	Hoist Brake failure(X24)		0.16437	0.22186	0.15267	Weibull	Beta = 1.0673, Eta = 1296.4724
Swing Mechanism(S5)	Rotate Frame Failure(X25)		0.40342	0.41185	0.18649	Weibull	Beta 0.5529, Eta = 859.7922
	Roller Failure(X26)		0.25811	0.33365	0.21678	Weibull	Beta 0.6056, Eta = 3005.4658
	Gearbox Failure(X27)		0.2647	0.25009	0.13801	Weibull	Beta 0.6053, Eta = 1925.0062
	Swing motor system(SE3)	Control system Failure(X28)	0.23044	0.22128	0.16382	Weibull	Beta = 0.9322, Eta = 1671.9531
		Swing Motor Failure(X29)	0.24788	0.15238	0.13605	Weibull	Beta = 0.7478, Eta = 1891.6205
		Swing Motor Failure(X30)	0.24788	0.15238	0.13605	Weibull	Beta = 0.7478, Eta = 1891.6205
Electrical Auxiliary(S6)	Exciter failure(X31)		0.27027	0.2601	0.19519	Weibull	Beta = 0.8145, Eta = 1828.4362
	M.G. Set Failure(X32)		0.26191	0.35192	0.09116	Weibull	Beta 0.6605, Eta = 304.1192
	Synchronous Motor Failure(X33)		0.3949	0.28466	0.27054	Weibull	Beta = 0.4304, Eta = 1231.2756
	DC Problem Failure(X34)		0.28279	0.32975	0.19313	Weibull	Beta 0.5491, Eta = 2544.4627
	Power Failure(X35)		0.5002	0.44704	0.21036	Weibull	Beta = 0.4801, Eta = 1213.2405
	Trailing cable Failure(X36)		0.28122	0.37899	0.17387	Weibull	Beta = 0.6875, Eta = 855.8271
Others subsystem(S7)	Compressor Failure(X37)		0.29051	0.27996	0.26911	Weibull	Beta = 1.4718, Eta = 4753.7684
	Lubrication Failure(X38)		0.19126	0.15906	0.14045	Weibull	Beta = 0.69183, Eta = 980.3494
	Guide Pulley Failure(X39)		0.41761	0.33778	0.18333	Weibull	Beta = 0.5116, Eta = 1633.5032
	Boom Light Failure(X40)		0.30353	0.21485	0.18697	Weibull	Beta = 1.5948, Eta = 2561.6374

4.7 Result

Results of the trend test and correlation test (ref Figure 4.14) for each components of the dragline have shown no trend and correlation presence in failure data. Thus, failure data is independent and identically distributed (IID) and suitable for modelling by theoretical parametric distributions. Best suitable distribution is obtained by a goodness-of-fit teat and results shows that all the components' failures are mostly following Weibull distribution (Ref table 4.2).

4.8 Summary

Failure data of the case study dragline has been collected for the study. As per collected data, dragline is divided into different subsystems. This failure data has been cleaned, outliners identified through the boxplot. Data has been tested for IDD. Based on the goodness-of-fit test, theoretical distribution and corresponding parameters has estimated for each component of dragline system.