Reliability, Availability and Maintainability Analysis of the Main Conveyor System in Underground Coal Mine: A Case Study of Churcha (RO) Mine

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Reliability, Availability and Maintainability Analysis of the Main Conveyor System in Underground Coal Mine: A Case Study of Churcha (RO) Mine

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by

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(Roll Number: 214MN1510)

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under the supervision of

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Certificate of Examination

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This is certify that the thesis entitled *"Reliability, Availability and Maintainability Analysis of the Main Conveyor System in Underground Coal Mine: A Case Study of Churcha (RO) Mine"*, being submitted by *PRITAM KUMAR*, Roll No. 214MN1510, to the National Institute of Technology, Rourkela for the award of the degree Master of Technology in Mining Engineering, is a bonafide record of research work carried out by him under my supervision and guidance.

The candidate has fulfilled all the prescribed requirements.

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This is to certify that the work presented in this Thesis entitled "*Reliability, Availability and Maintainability Analysis of the Main Conveyor System in Underground Coal Mine: A Case Study of Churcha (RO) Mine*" by "*Pritam Kumar*", Roll Number 214MN1510, is a record of original research carried out by him under my supervision and guidance in partial fulfilment of the requirements for the degree of *Master of Technology in Mining Engineering*. Neither this project report nor any part of it has been submitted for any degree or diploma to any institute or university in India or abroad.

Dr. A. K. Gorai

This thesis is dedicated to my lovely parents

Pritam Kumar

Declaration of Originality

I, *Pritam Kumar*, Roll Number *214MN1510* hereby declare that this thesis "*Reliability, Availability and Maintainability Analysis of the Main Conveyor System in Underground Coal Mine: A Case Study of Churcha (RO) Mine*" represents my original work carried out as a postgraduate student of NIT Rourkela and, to the best of my knowledge, it contains no material previously published or written by another person, nor any material presented for the award of any other degree or diploma of NIT Rourkela or any other institution. Any contribution made to this research by others, with whom I have worked at NIT Rourkela or elsewhere, is explicitly acknowledged in the dissertation. Works of other authors cited in this thesis have been duly acknowledged under the section "References". I have also submitted my original research records to the scrutiny committee for evaluation of my dissertation.

I am fully aware that in the case of any non-compliance detected in future, the Senate of NIT Rourkela may withdraw the degree awarded to me on the basis of the present dissertation.

May 26, 2016

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Abstract

Estimation of reliability, maintainability and availability assumes an important role in performance evolution of mining system or equipment. Reliability forecasts are necessary for every type of the machinery, similar to maintenance planning, production planning, reliability assessment, fault detection in the production system of mine, and risk evaluation. The mining system's reliability, maintainability and availability have assumed great significance in present years due to a competitive environment and overall operating condition and production purpose. The performance of the system depends on reliability and availability of the machinery used, working environment, maintenance, operation process and specialized skill of operators, etc. The aim of the proposed study is to analyze operating reliability, maintainability and availability of the main conveyor system in an underground coal mine. The study uses the failure and repair data of the main conveyor system of Churcha (RO) coal mine in India. The main conveyor system in the mine has seven subsystems. This analysis has developed a method to identify the critical and sensitive subsystems or components of the main Conveyor system that need more attention for improvement. In this research work, we suggest the way to improve the reliability and availability of a repairable system. In the way, the concept of importance measures must be used to prioritize the components or subsystems for availability improvement processes. Availability significance measures the criticality of each component based on different points of view such as availability, failure rate, and repair rate of each subsystem. The reliability and availability of repairable systems can be enhanced by applying proper maintenance strategies. For each subsystem, best fit models were selected for reliability and maintainability analyses. The empirical data of the conveyor system at Churcha (RO) mine of SECL are used as a case study for reliability, availability and maintainability strategies analysis.

The study shows that the reliability and maintainability analysis is greatly helpful for deciding maintenance intervals, planning and organizing maintenance of main conveyor system in the mine. The outcomes demonstrate that availability and reliability significance measures can be utilized as a rule for organizing the efforts for reliability and availability improvement of a system.
Keywords: Reliability, Availability and Maintainability, Maintenance, repairable system, Conveyor system, Coal mine.

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Acronyms

RAM	Reliability, Availability & Maintainability
UG	Under Ground
IID	Independent and Identically Distributed
K-S	Kolmogorov-Smirnov
PDF	Probability Density Function
PM	Preventive Maintenance
TBF	Time Between Failure
TTR	Time To Repair
MTBF	Mean Time Between Failure
MTTR	Mean Time To Repair
CDF	Cumulative Distribution Function
CTBF	Cumulative Time Between Failure
CTTR	Cumulative Time To Repair
MLE	Maximum Likelihood Estimation
α	Shape/Slope Parameter
γ	Location Parameter
μ	Mean Of The Natural Logarithm
σ	Standard Deviation
β	Scale parameter
λ	Failure rate

Chapter 1

Introduction

1.1 Introduction

This chapter presents the background of the topic for this research and research problem. Furthermore, it presents the main aim and objectives, research questions, and limitations, before specifying the outline and structure of the research study.

1.1.1 Background

The study of reliability, maintainability and availability of a system have assumed great significance in recent years due to a competitive environment and overall operating and production costs. Today's technological systems in the mines characterized by a high level of complexity. The requirements for the availability and reliability study of such systems are very much desirable.

Mining history can be traced back many thousand years. The methods and equipment used was inefficient and required many workers for the small amount of goods. Today's situation is different. In the mine, the mining equipment is more efficient & the money spent on equipment and expertise is huge and increasing. It creates a need for improvement of the already efficient process of extracting goods. The expenditure is increasing, and the demand for high quality and quantity of goods is increasing [1]. The increasing need for energy and to keep expenditure low creates a need to optimize production lines. This process is more complex and challenging than before. There is an expectation that machinery, equipment and technology are supposed to be available at all times, ready for use and have a high performance. In some areas the industry is harder to improve, the cost of improvement work can seem high because the reward is not obvious at first. It may, therefore, be very hard to increase the reliability or availability of a system in the mining industry [2]. The machinery is increasing in complexity and size, which adds to the list of challenges in the mining industry.

Economic is important in today's mining industry, with the correct use one can gain high reliability which causes the maintenance costs to lower and therefore increase the profit [3]. A method to improve this can be to simply an availability and reliability approach to increase the availability of the production line. The use of this method can save resources in many aspects, like logistic, unnecessary repairs, more production, etc. By using a reliability analysis, the Knowledge of system increases with this knowledge one is more capable of making decisions when changing the system or operating circumstances [2].

Most mine production lines consist of many subsystems and many components. Each subsystem and component affect the total availability and reliability of the total production line. Therefore, each subsystem and component should be analyzed to determine how the component affects the availability and reliability of the overall system. To increase the reliability of any machinery, it is needed to study it to determine the necessary improvements or modifications that should be executed. When completing these objectives one should be able to improve the production of the mine and increase the availability and reliability of the mine [1].

1.1.2 Research problem

The mining equipment is increasing in size and complexity with time, and this demands a higher level of performance and reliability for its economical operation [1]. According to Blischke and Murthy (2003), the consequences of failure of a system are many and varied. The failure depends on the item, but nearly every failure has an economic impact. A failure in equipment or facility results not only in the loss of productivity, but also in loss of quality, timely services to customers, and may even lead to safety and environmental problems which destroy the company image. For example, the consequences of failures can be to such a degree that the system is not profitable and therefore not used, causing loss of potential workplaces and industrial expansion. Therefore, optimizing and improving the performance of a mine production line is more demanding and complex than ever. To improvement the performance of the system, it needs to be analyzed. Improving the systems performance means achieving maximum production that the system can handle. However, there is a cost for improving the system. So improvement should be made where it increases the profitability.

A mine production line consists of several subsystems and components. Each subsystem and each component affect the total availability and reliability performance of the total production line [1]. Therefore, the performance of each subsystem and component should be analyzed to determine how each subsystem and component affects the availability and reliability performance of the whole production line. The result of such an analysis will help to identify the weakest areas of the mine production line and also increase the knowledge about the system. With this knowledge, one is more capable of making decisions when changing the system or operating circumstances. Therefore, a focus on reliability, maintainability and availability analysis are critical for the improvement of the mining equipment performance ensuring that it is available for production as per production schedules.

It should also be mentioned that the mining activities, in general, are carried out in complex and uncertain environments. In such operational environments, there are many factors (e.g. ineffective blasting, weather, maintenance strategy, geology, etc.) that can directly or indirectly affect the hazard rate or reliability performance of the mining equipment such as reliability and maintainability. Therefore, it is a challenge to analysis the effect of the operational environment condition on the reliability performance of the equipment. According to the literature, the effects of operational conditions on the performance of the equipment are poorly researched. A big issue is that the historical data is recorded very poorly if even available. If there is a system for data collection, this is usually from the common data, such as failure occurrence and cause, which is not included the operational condition which the failures do occur. The focus on data collection considering operational conditions is not widely known or used.

1.1.3 Research questions

Based on the research problem described, the following research questions have been formulated:

- What is the various subsystem in the main conveyor system?
- How the failure and repair data of the conveyor system are distributed?
- What is the scheduled maintenance of the subsystem for improving the overall availability of the system?

1.1.4 Objectives of the Research

The primary objective of the proposed study are as follows:

- Analyze the availability, reliability and maintainability of main conveyor system in Churcha (RO) coal mine.
- Determination of scheduled maintenance hour of each subsystem for improving the reliability of the system to 80%.

1.1.5 Organization of the Thesis

The thesis contains five chapters.

Chapter 1 presents the background of the topic for this research and research problem. Furthermore, it presents the main aim and objectives, research questions, and outline and structure of the thesis.

Chapter 2 presents the past studies in the area of reliability, availability, and maintainability of the mining machinery. this includes the aspects of reliability, availability, and maintainability theory with respect to probability and statistics.

Chapter 3 demonstrates the materials and methods adopted in the proposed study. The data type and collection method for the proposed study are also explained in this chapter.

Chapter 4 demonstrates the data analysis and results. This chapter also presents the detailed discussion of the results.

Chapter 5 presents the conclusions of the study.

Chapter 2

Literature Review

2.1 Introduction

Reliability, availability and maintainability analyses of mining machineries are very much essential for smooth production. To understand the mathematical explanations of reliability, availability and maintainability, some basic probability and statistics need to be addressed. The upcoming sections will present an introduction to basics of probability and statistics along with the definitions and descriptions of reliability, availability and maintainability before describing the concept of importance measures.

2.1.1 Probability and statistics

Probability and statistics are two related subjects but cover separate theoretical disciplines. Statistical analysis often uses probability distributions, and the two topics are often studied together. However, probability theory contains much that is mostly of mathematical interest and not directly relevant to statistics.

Probability is the branch of mathematics that studies the possible outcomes of given events together with the outcomes' relative likelihoods and distributions. In common usage, the word "probability" is used to mean the chance that a particular event (or set of events) will occur expressed on a linear scale from 0 (impossibility) to 1 (certainty), also expressed as a percentage between 0 and 100%. The analysis of events governed by probability is called statistics.

Statistics is a discipline that allows investigators to evaluate conclusions derived from sample data. In practice, statistics refers to a scientific approach used to:

- Collect data.
- Interpret and analyze data.
- Assess the reliability of conclusions based on sample data

2.1.1.1 Probability density function (PDF)

A statistical measure that defines a probability distribution for a random variable and is often denoted as f (x). Let X be a continuous random variable. Then a probability distribution or probability density function (PDF) of X is a function f (x) such that for any two numbers a and b with a ≤ b,

$$P(a < X < b) = \int_a^b f(x)\,dx \tag{2.1}$$

That is, the probability that X takes on a value in the interval [a, b] is the area above this interval and under the graph of the density function. The graph of f (x) is often referred to as the density curve. As probabilities cannot be negative and never greater than 1, the two following properties [shown by equation (2.2) and equation (2.3)] of the PDF are always true [4]:

$$\int_{-\infty}^{\infty} f(x)\,dx = 1 \tag{2.2}$$

$$f(x) \geq 0 \tag{2.3}$$

2.1.1.2 Cumulative distribution function (CDF)

A function that gives the probability that a random variable is less than or equal to the independent variable of the function. For a random variable X, the CDF is the function F(x), defined by [4]:

$$F(x) = P(X \leq \mathrm{x}) = \int_0^x \mathrm{f(x)}\,dx \tag{2.4}$$

Where X is the random variable, which is the sum or integral of the probability density function of the distribution & x is the independent variable.

2.1.2 Reliability

One commonly used the definition of reliability is “ the ability of an item to perform a required function under given conditions for a given time interval” [5].

Reliability can also be defined probabilistic as, the probability that an item (component, subsystem, or system) or process operates properly for a specified amount of time (design life) understated use conditions (both environmental and operational conditions) without failure [6]. In mathematical terms, the time to failure T, of an item, is defined as a continuous random variable. The reliability, which is a function of time t, will then be expressed as the probability that the time to failure T, is longer than the operating time t. This means that the reliability is the probability that the failure has not occurred at time t, and is given by [7]:

$$R(\mathrm{t}) = P(\mathrm{T} > \mathrm{t}) \tag{2.5}$$

Where, R(0) = 1 and R(t) ≥ 0.

The reliability function can be derived from the cumulative distribution function F(x). In reliability-sense, the CDF is the probability that the random time to failure T is less than or equal to the operating time t. The CDF for reliability is denoted F(t), and in combination with the fact that the area under the probability density function is always equal to 1, the reliability function is expressed as:

$$R(\mathrm{t}) = P(\mathrm{T} > \mathrm{t}) = 1 - \mathrm{F(t)} \tag{2.6}$$

The relation between the CDF and the PDF is given as:

$$F(t) = \int_0^t \mathrm{f(t)}\, dt \tag{2.7}$$

And reliability function is then obtained as:

$$R(t) = 1 - \int_0^t \mathrm{f(t)}\, dt \tag{2.8}$$

$$R(t) = \int_t^\infty \mathrm{f(t)}\, dt \tag{2.9}$$

Where f (t) is probability density function of time to failure.

The unreliability, or in other words, the probability that the failure has occurred, is then the opposite and is defined as the probability that time to failure T, is equal and smaller than to operating time t. This is the same as the CDF and is expressed as [7]:

$$F(t) = P(\mathrm{T} \leq \mathrm{t}) \tag{2.10}$$

$$F(t) = \int_0^t \mathrm{f(t)}\, dt \tag{2.11}$$

2.1.3 Availability

One commonly used the definition of availability is “the ability of an item to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided” [5].

Availability can also be defined as “the probability that a system or component is performing its required function at a given point in time or over a stated period when operated and maintained in a prescribed manner” [8].

There are different types of availability, such as pointwise, interval and limiting. However, this research study focuses on the steady-state availability. The reason is that this type of availability is the most practical one to use.

- **Steady-state availability or limiting availability**: the mean of the instantaneous availability under steady-state condition over a given time interval. Under certain condition, for instance, constant failure rate and repair rate, the steady-state availability may be expressed by the ratio of the mean up a time to the sum of the mean up time and mean down time. Under these conditions, asymptotic and steady-state availability are identical and often simply referred to as availability. The steady system availability (or steady state availability, or limiting availability) of a system, which is defined by

$$A = \lim_{t \to \infty} A(t) \tag{2.12}$$

Where, A is Steady-state availability or limiting availability and A(t) is mean availability at given time interval t. This quantity is the probability that the system will be available after it has been run for a long time, and is a very significant measure of performance of a repairable system.

Depending on the definitions of uptime and downtime the steady-state availability can be divided into following categories:

- **Inherent availability**: inherent availability is the probability that a system or equipment, when used under stated conditions, is an ideal support environment (i.e., readily available tools, spares, maintenance personnel, etc.), which will operate satisfactorily at any point in time as required [9]. It excludes preventive or scheduled maintenance action, logistic delay time, and administrative delay time, and is expressed as [10]:

$$A = \lim_{t \to \infty} A(t) = \frac{MTBF}{MTBF + MTTR} \tag{2.13}$$

  Where, MTBF is mean time between failure and MTTR is mean time to repair.
  Inherent availability is based solely on the failure distribution and repair time distribution. It can be viewed as an equipment design parameter, and reliability-maintainability trade-off can be based on this interpretation [9].

- **Achieved availability**: Achieved availability is the probability that a system or equipment, when used under stated conditions is an ideal support environment (i.e., readily available tools, spares, personnel, etc.), which will operate satisfactorily at any point in time. The achieved availability is defined as [9]:

$$A = \frac{MTBF}{MTBF + M} \tag{2.14}$$

Where, MTBF is mean time between failure & M is the mean active maintenance time.
The mean time between maintenance operations (MTBM) includes both unscheduled and preventive maintenance and the mean active maintenance time (M). If it is performed too frequently, preventive maintenance can have a negative impact on the achieved availability even though it may increase the MTBF. Preventive maintenance intervals resulting in frequent downtimes have availability less than the inherent availability. As the preventive maintenance interval increases, the achieved availability will reach a maximum point and then generally approach the inherent availability.

- **Operational availability**: operational availability is the probability that a system or equipment, when used under stated conditions in an actual operational environment, will operate satisfactorily when called upon. The operational availability is defined as [9]:

$$A = \frac{MTBF}{MTBF+MDT} \tag{2.15}$$

Where MDT is the mean maintenance downtime and includes maintenance time (M), logistics delay time and administrative delay time.

2.1.4 Maintainability and Maintenance

The definition of maintainability is “the ability of an item under given conditions of use, to be retained in, or restored to, a state in which it can perform a required function when maintenance is performed under given conditions and using stated procedures and resources [5].

Maintainability can also be defined probabilistic as the probability that a given active maintenance action, for an item under given conditions of use can be carried out within a stated time interval, when the maintenance is performed under stated conditions and using stated procedures and resources [11].

In mathematical terms, the time to repair T, of an item, is defined as a continuous random variable. This random variable will have a probability density function like the reliability function described in section 2.1.2. However, maintainability addresses the probability that the repair has happened, and therefore the maintainability, which is a function of time t, is expressed as [1]:

$$M(\mathrm{t}) = P(\mathrm{T}' \leq \mathrm{t}) = \mathrm{F}'(\mathrm{t}) \tag{2.16}$$

Where $F'(t)$ is the cumulative distribution function of the time to repair and T' is the random time to repair variable.

In other words, maintainability is the probability that the item will be repaired within a time t. Saying that a system or a component has a maintainability of 80 % in one day, will thus mean that there is 80 % probability that the system or component will be restored or repaired within a day. The probability density function for the maintainability is denoted $f'(t)$, then the maintainability function M(t) can be further expressed as [1]:

$$M(t) = \int_0^t f'(t)\,dt \qquad (2.17)$$

Where f’ (t) is defined to be the probability distribution for the repair time.

For maintenance actions, there exist three basic types, namely corrective maintenance, preventive maintenance, and inspection. In short, the three represent the following:

- Corrective maintenance is the maintenance actions performed after failure of the item. It is the actions necessary to restore the item back to operating state. The actions are typically repair or replacement of components or subsystems and is performed randomly as failure times are not possible to know in advance.
- Preventive maintenance is the maintenance actions performed before failure of the item. It is the actions intended to prevent the failure. The actions can be many but are typically component repairs, lubrication, and overhauls. For preventive maintenance to be necessary and beneficial, two conditions have to be satisfied. Firstly, the system or component have to experience wear-out, implying an increasing failure rate. Secondly, the overall cost of the preventive maintenance actions has to be less than the overall cost of the corrective maintenance actions.
- Inspections are meant to discover hidden or future failures. The inspection techniques can be many and consist of both visual and non-visual techniques. Common for all inspections is that they do not alter the condition or age of the equipment, as no repair or replacement takes place. An inspection can lead to repair or replacement but in that case, the repair is either classified as corrective or preventive maintenance.

These maintenance types can be divided further into subtypes and disciplines. Some of the most common are condition-based maintenance, periodic maintenance, design-out maintenance, and opportunity maintenance. Which subtypes and disciplines that are used in different companies and plants depended on the chosen and prepared maintenance strategy and maintenance plan. It is, however, most common with a combination of all three main maintenance types with associated disciplines, depending on the probability of failure and consequence of failure both on health, safety, and environment, production, and quality.

2.1.5 Hazard rate

Another measure of interest in reliability estimations and the evolution of failures, is the probability of failure of an item in a small interval dt, given that the item has not failed until the time of the beginning of the interval. This probability is given by the product of the small interval dt, and the conditional probability of failure, called the hazard rate usually denoted h(t), which is a function of time t [12]. This probability can be expressed as the following:

$$h(t)dt = \frac{f(t)dt}{R(t)} \tag{2.18}$$

Where t is the random time to failure variable, f(t) is the probability density function, R(t) is the reliability function, and the hazard rate h represents the number of failures per unit time t. The hazard rate defines the lifetime distribution of the units, meaning the statistical probability distribution of the time to (first) failure [5]. Another commonly used notation for the hazard rate is λ. This notation has, in this study, been used for the rate of the exponential distribution, and to avoid the confusion, the hazard rate is denoted h. The relation between the hazard rate, probability density function, and reliability function is given as the following [7]:

$$h(t) = \frac{f(t)}{R(t)} \tag{2.19}$$

2.1.6 Probability distributions functions

The present study uses six common probability distribution functions for reliability analyses. The mathematical form of the six functions are explained below:

- **Weibull Distribution with 3-Parameter**

The Weibull distribution is widely used in reliability and life data analysis due to its versatility. Depending on the values of the parameters, the Weibull distribution can be used to model a variety of life behaviors. We will now examine how the values of the shape parameter, α, and the scale parameter, β, affect such distribution characteristics as the shape of the curve, the reliability, and the failure rate. Note that in the rest of this section we will assume the most general form of the Weibull distribution, (i.e., the 3-parameter form). The appropriate substitutions to obtain the other forms, such as the 2-parameter form where $\gamma = 0$, and γ is the location parameter and t which is the time parameter [11]. Probability density function for Weibull 3 parameter distribution is given in equation (2.20)

$$f(t) = \frac{\alpha}{\beta}\left(\frac{t-\gamma}{\beta}\right)^{\alpha-1} e^{-\left(\frac{t-\gamma}{\beta}\right)^{\alpha}} \quad (2.20)$$

- **Weibull Distribution with 2-Parameter**

The probability density function for Weibull 2-parameter distribution is given in equation (2.21):

$$f(t) = \frac{\alpha}{\beta}\left(\frac{t}{\beta}\right)^{\alpha-1} e^{-\left(\frac{t}{\beta}\right)^{\alpha}} \quad (2.21)$$

The location parameter (γ) is equal to zero.

- **Lognormal Distribution with 3-Parameter**

Lognormal distribution is one of the distributions commonly used for reliability or modeling lifetimes and is particularly useful for modeling data which are long-tailed and positively skewed. The lognormal 3P has three parameters. The first one is μ, the mean of the natural logarithm of TBF, the second one is σ, the standard deviation of the natural logarithm of TBF and the third is γ, the location parameter [11]. The probability density function for Lognormal 3-parameter distribution is given in equation (2.22):

$$f(t) = \frac{1}{(t-\gamma)\sigma\sqrt{2\pi}} e^{\left\{-\frac{[ln(t-\gamma)-\mu]^2}{2\sigma^2}\right\}} \quad (2.22)$$

- **Lognormal Distribution with 2-parameter**

The probability density function for Lognormal 2-parameter distribution is given in equation 2.23.

$$f(t) = \frac{1}{t\sigma\sqrt{2\pi}} e^{\left\{-\frac{[ln(t)-\mu]^2}{2\sigma^2}\right\}} \quad (2.23)$$

In the above equation, the location parameter (γ) is equal to zero.

- **Normal Distribution**

The normal distribution is the most widely known and used in all distributions. Since the normal distribution approximates many natural phenomena so well, it has developed into a standard of reference for many probability problems. There are two parameters, μ is the mean of TBF, σ is the standard deviation of TBF. The mathematical formula for probability density function of normal distribution is shown in equation (2.24).

$$f(t) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(t-\mu)^2}{2\sigma^2}} \tag{2.24}$$

- **Exponential Distribution**

Exponential distribution plays an essential role in reliability engineering because it has a constant failure rate, λ. This distribution has been used to model the lifetime of mechanical and electrical components of a system. The probability density function of the exponential distribution is shown in equation (2.25).

$$f(t) = \lambda e^{-\lambda(t-\gamma)} \tag{2.25}$$

2.2 Literature on Reliability Analysis of Mining Machineries

In this section, the specific studies related to reliability, availability and maintainability of mining machinery are demonstrated.

Rocco and Moreno (2003) used Monte Carlo Simulation and Support Vector Machine (SVM) for the reliability evaluation of machinery. In their study, they presented the SVM, built from a little fraction of the total state space, which produced very close reliability estimation with relative error less than 1%. They inferred that model based on SVM takes the most informative patterns in the data (the support vectors) which can be used to evaluate approximate reliability importance of the components [13].

Barabady (2005) studied the reliability and maintainability of crushing plants of Jajarm bauxite mine of Iran. The crushing plants of the mine were divided into seven subsystems for the analyses. Reliability analysis was done for each subsystem. The parameters of some idealized probability distributions, such as Weibull, Exponential, Lognormal distributions, had been estimated by using ReliaSoft's Weibull++ 6 software. Reliability of both crushing plants and its subsystems has been estimated at different mission times with their best-fit distribution. Analysis of the total downtime, breakdown frequency, reliability, and maintainability characteristics of different subsystems shown that the reliability of crushing plant 1 and crushing plant 2 after 10 hours reduce to about 64% and 35% respectively. The study results revealed that reliability and maintainability analysis is very useful for deciding maintenance intervals. It is also useful for planning and organizing maintenance [14].

Barabady and Kumar (2005) studied the reliability analysis of mining equipment of a crushing plant at the Jajarm Bauxite Mine of Iran. Reliability is an important consideration in the planning, design, and operation of engineering systems. As the size and complexity of mining equipment continue to increase, the implications of equipment failure became ever more critical. One method to mitigate the impact of failures is to improve the reliability of the equipment. One of the purposes of system reliability analysis is to identify the weakness in a system and to compute the effectively related consequence of a component failure. The performance of mining machines depends on the reliability of the equipment used, the operating environment, etc. It is important to select a suitable method for data collection and reliability analysis. This paper was divided into two parts. The first part introduced a methodology for reliability and availability analysis of mining equipment. The second part presented a case study describing the reliability analysis of a crushing plant at Jajarm Bauxite Mine in Iran [15].

Barabady and Kumar (2005) studied the availability improvement of the system. The concept of importance measures could be used to prioritize the components or subsystems for the availability improvement process, and, therefore, some importance availability measures based on the failure rate and repair rate are presented which can be used as a guideline for the development and improvement strategy. Each component should be assigned a value between 0 and 1 and the component with a greater value would have a greater influence on the availability of the system. In this study, the availability importance of a component is defined as a partial derivative of the system availability with respect to this component availability [16].

Furuly et al. (2010) studied the **r**eliability analysis of mining equipment considering operational environments, failure of the complex, sophisticated and so expensive mining equipment may have a lot of consequences on production costs, safety and the environment. Hence, the reliability analysis is required to predicate the failure time and hazard rate of mining equipment. Mining activities, in general, are carried out in complex and uncertain environments. In such operational environments, there were many factors (e.g. ineffective blasting, weather, maintenance strategy, geology, etc.) that were directly or indirectly affected the hazard rate or reliability performance of the mining equipment. Therefore, the statistical approach for reliability analysis must be selected in such a way as to be able to quantify the effects of the all those influence factors. In this paper the application of a Proportional Hazard Model (PHM) to quantify the effects of climate conditions on the hazard rate of the Stacker belt in The Svea coal mine in Svalbard, Norway are discussed. The result of the study shown that the hazard rate of the Stacker Belt in winter could have been four times more than the rest of the year, which needs to be considered in the maintenance plan of the mine [17].

Furuly et al. (2010) studied the reliability and maintainability analysis of the main conveyor in the Svea coal mine of Norway. Reliability and maintainability of the mining industry have been more in focus than ever; the mining system became more complex and the equipment more expensive to repair or modify. This paper presented a case study describing a reliability and maintainability analysis of the main conveyor system of the Svea coal mine located in Svalbard, Norway. The conveyor system included several separate conveyors. In this study, the main six conveyors of the whole system were selected for the analysis. The failure and repair data of the conveyors were collected for the whole year of 2010 using maintenance and daily reports. The date was analyzed, and the result showed that the availability of six conveyors is 96.44% for one year of operation. However, the reliability of these conveyors needs to be improved [18].

Gupta et al. (2011) proposed some aspects of Reliability and Maintainability in Bulk Material Handling System Design and Factors of Performance Measure, In Design and selection of bulk Material Handling Equipment and Systems. In this paper, authors discuss some areas of belt and pneumatic conveying design, excavator stacker and reclaimer surface miners design selection and application, testing and examination of the causes of equipment damages, high pressure grinding roll technology, equipment related injuries, reliability and maintainability of equipment aspects of ore degradation during handling and modeling [19].

Boban et al. (2013) implemented TPM technique in industries for enhancing the overall equipment effectiveness. As a result, availability, reliability, maintainability and safety (RAMS) can be increased. In this paper author plans for implementing TPM which are 5S, Jishu Hozen, Kaizen and abnormality classification leads to more equipment effectiveness in the company [20].

Kajal et al. (2013) proposed a steady state availability optimization of the coal handling system by using MATLAB's Genetic Algorithm tool. In this paper, author presents the values of failure and repair rates taken from history maintenance sheet and optimize it from 96.20% to 98.87% i.e. the increase of 2.67% through mathematical formulation and is carried out using probabilistic approach and Markov birth-death process is used to develop the Chapman-Kolmogorov difference differential. To achieve the optimum availability level, the corresponding repair and failure rates of the subsystems should be maintained. The failure rates can be maintained through good design, reliable machines, proper preventive maintenance schedule, and providing standby components, etc. The corresponding repair rates can be achieved by employing more trained workers and utilizing better repair facilities [21].

Mohammadi et al. (2015) studied the performance measurement of mining equipment. In this study, various indicators such as cycle time, bucket-fill factor, material-swell factor, reliability, availability, maintainability, utilization, and production efficiency have been in vogue since long for evaluating the performance of belt equipment. The present aims at reviewing the available pertinent literature in the subject field and deals with various aspects of performance measurement of belt equipment in the mining industry. These indicators which are used for evaluating the performance of belt equipment are described herewith. It is worthy to note that, the term of Belt has been introduced as an acronym, in the present work, to cover the entire variety of equipment that have a bucket, which is capable of excavating, loading, hauling and dumping or even for transporting the excavated material (as in Dumper) [22].

Kalra et al. (2015) studied operational analysis of mining equipment in opencast mine using overall equipment effectiveness (OEE). The concept of TPM was given by Nakajima in the year 1971 in Japan, which states that it is the joint responsibility of the operators and the maintenance staff to upkeep the machines. The operator of the machinery needs to be trained to perform many small issues of maintenance and fault finding. Small teams of production and maintenance staff should be formed for reducing the downtime for effective utilization of the equipment and hence increase the life cycle of equipment. The main objective of the TPM is to reduce the breakdowns to zero, zero defects in operation and maintenance so that there are almost zero wastage and zero accidents [23]

Chapter 3

Materials and Method

3.1 Brief Description of Conveyor Belt

Conveyor belt is broadly utilized as a part of the mineral industry. Underground mine transport, opencast mine transport, and handling plants send transport lines of various types to receive the particular occupation prerequisites. In underground mine transport, belt conveyor can give continuous transportations facility from pit base to the surface. The component of a typical conveyor belt is shown in Figure 3.1. The descriptions of the major components are given below:

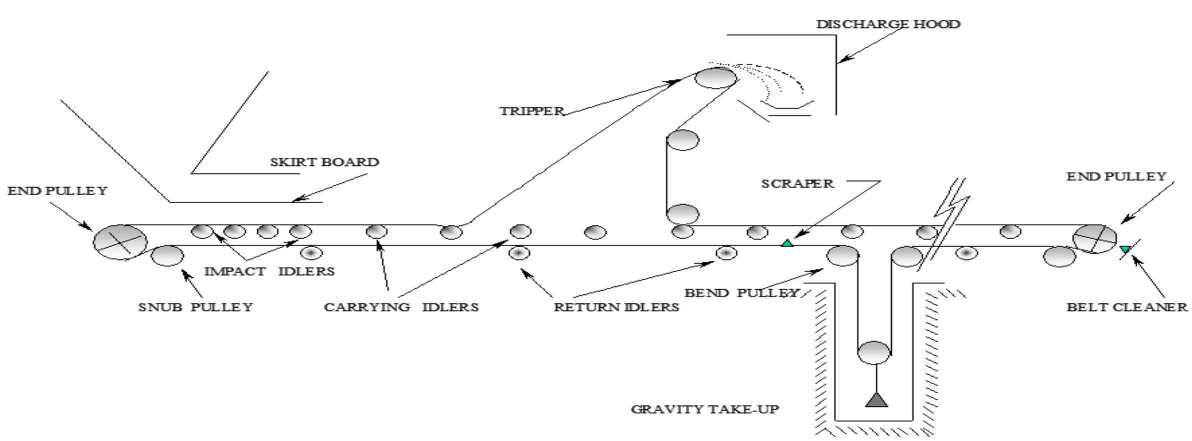


Figure 3.1: Components of the belt conveyor

- **Idlers:** Idlers are mounted on a bolstered edge, which can be portable or lasting. The conveying side of the belt is bolstered on the transporter rollers sets. An arrangement of three rollers is organized to frame a trough for the troughed belt transport. The arrival side of the belt is upheld on straight return idlers. The separating of the idlers is resolved to take into account the belt hang between the idlers. The list relies on upon the belt strain, belt width, belt properties and the payload per meter of the belt. The idlers are determined by its length and distance across. These parameters are chosen in light of the required belt speed for the specific width of the belt.

- **Pulley:** A transport line framework utilizes distinctive sorts of pulleys like end pulley, censure pulley, twist pulley and so forth. The end pulleys are utilized for driving and here and there for making tensioning game plans. Scorn pulleys build the edge of wrap subsequently expanding the successful tension in the belt. The pulley breadth relies on upon the belt width and belt speed.

  Pulleys are utilized for giving the drive to the belt and additionally to maintain the best possible tension to the belt.
- **Belt Drive:** Belt drive is given ordinarily at the release closes, however, it might be given through the head end or middle pulley by coupling the pulley shaft to the lessening rigging's yield shaft. The coupling is chosen to take into account the heap qualities and applications. Adaptable coupling or liquid couplings are frequently utilized.
- **Conveyor Support:** The support of conveyor is ordinarily an auxiliary casing. Contingent upon the circumstance the structure can be mounted on the floor or a slip. The primary occupation of the support is to give the belt a chance to keep running without getting skewed. Contingent upon circumstances the support can be made moving sort. In such cases idler, a wheel mounted or crawler mounted stage keeps the fundamental procurement to bolster the idlers on which the conveyor runs.
- **Take-up:** This is utilized to keep up the best possible tension of the belt for compelling power transmission. The purpose of the Take-up as takes into account stretch and shrinkage of the belt.

3.2 Study Area

3.2.1 Mine Profile

The project profile of the mines and major equipment used in the mine are described in this section. The main conveyor system of the mine consists of seven sub-components for effective transportation of coal from the mines. Though, the production system in the mine uses various types of machinery, our main focus in the present study is to analyze the main conveyor belt system. This is one of the important components of the mine production system and requires high initial and operational cost. The location of the study mine [Churcha (RO) mine] is shown in Figure 3.2. The mine is operated under the management of South Eastern Coalfield Limited (SECL).

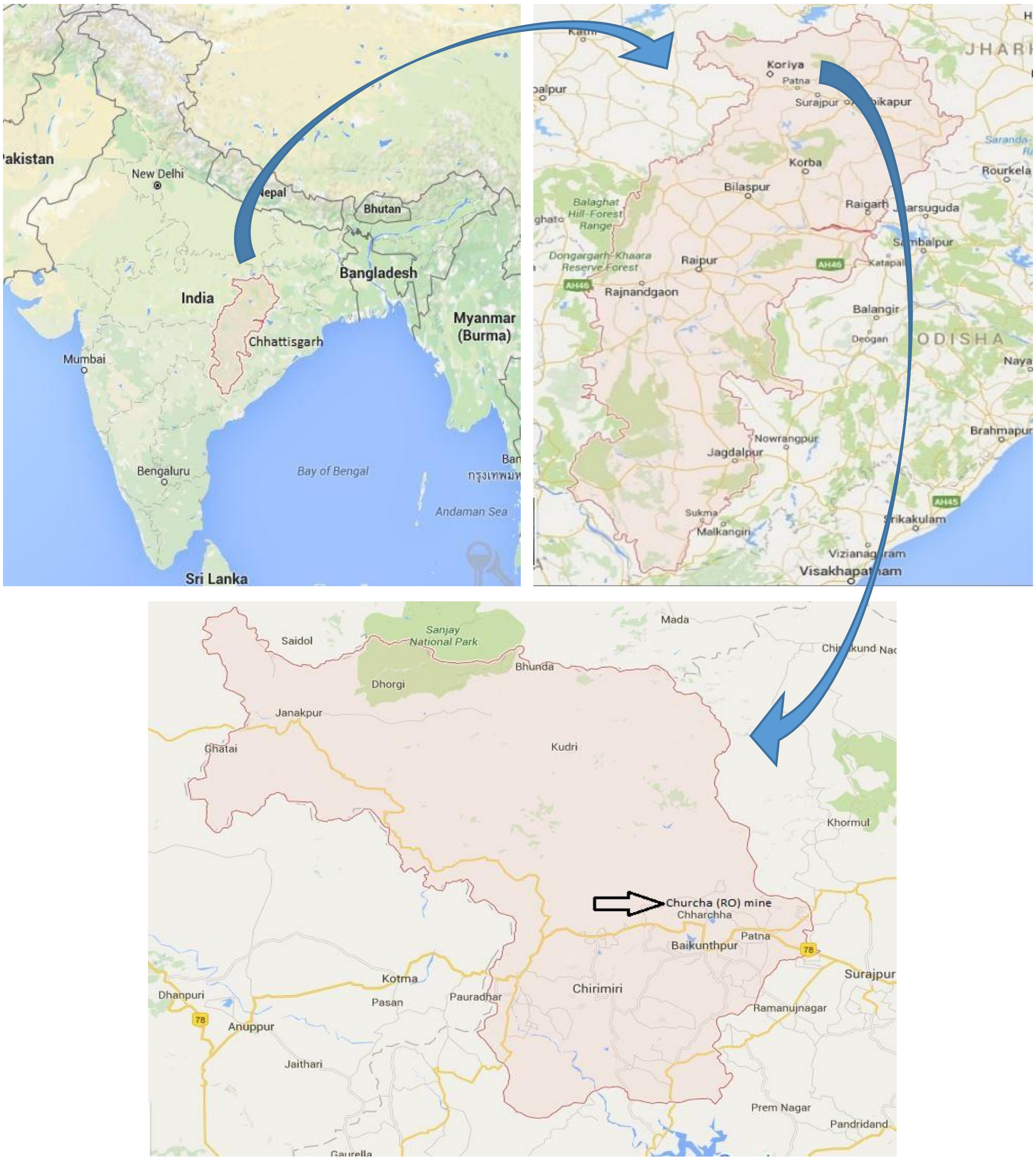


Figure 3.2: Location of Churcha (RO) mine

Churcha (RO) mine is located at district Koriya and the state of Chhattisgarh. Churcha (RO) mine is one of the oldest underground mines in India, and the specific information of the Churcha (RO) mine is given in Table 3.1. The continuous miner is used for excavation of coal from the Churcha (RO) mine. There are two continuous miners are in operation in the mine.

The capacity of the mine is 1.4 MTY of Coal. The manpower of the mine is 2541. In that way, there are a different kind of skill manpower available for the different work environment, that is, executive, skilled, semi-skilled and non-skilled.

Table 3.1: Churcha (RO) mine profile

SL. No.	Description	Detail
1	Type of Mine	UNDER GROUND
2	Location	23.25°N 82.55°E
3	Established	28.11.1985
4	Head Quarter	BILASPUR (CG)
5	Capacity of Mine	1.4 MTY
6	Technology	2 SETS OF CM
7	Man power	2541

3.2.2 Equipment Details of Churcha (RO) Mine

The smooth operations of the mining equipment are essential for production capacity, production time, and safety purposes. The primary operations require in underground mining are rock breakage and material handling. In Churcha (RO) mine, there are a different type of machinery used for different purposes like Haulage system for material handling, Manriding system for movement of manpower, Conveyor belt for transportation of coal, etc.

The specific details of the equipment are listed the Table 3.2.

Table 3.2: Equipment detail of Churcha (RO) mine

Sl. No.	Name of Equipment	Nos on Roll	Nos Available for Use
1	Winder	1	1

2	Haulage	15	15
3	SDL	0	0
4	LHD	19	19
5	Shearer/Longwall	0	0
6	Main Pump	41	37
7	Main Ventillation	3	3
8	Belt Conveyor	51	49
9	Chain Conveyor	0	0
10	Transwitch Unit	43	36
11	Continuous Miner	0	0
12	Manriding Haulage	1	1

3.2.3 Production layout of Churcha (RO) Mine

There are two faces of working field, West Face and East Face. The production line will be affected by the unwanted failure of the system which is using in the main line for production. In the production line, there is a different type of conveyor belt used. Figure 4.3 shows the total production line of the Churcha (RO) mine. The main conveyor system there is seven subsystems present in the mine for transportation of coal from the mine. All the seven conveyor subsystem is in series i.e.C1, C2, C3, C4, C5, C6 and C7 respectively. Figure 3.3 presents the flow of coal in the mine by the different type of conveyor belt like face belt, gate belt, main belt, etc.

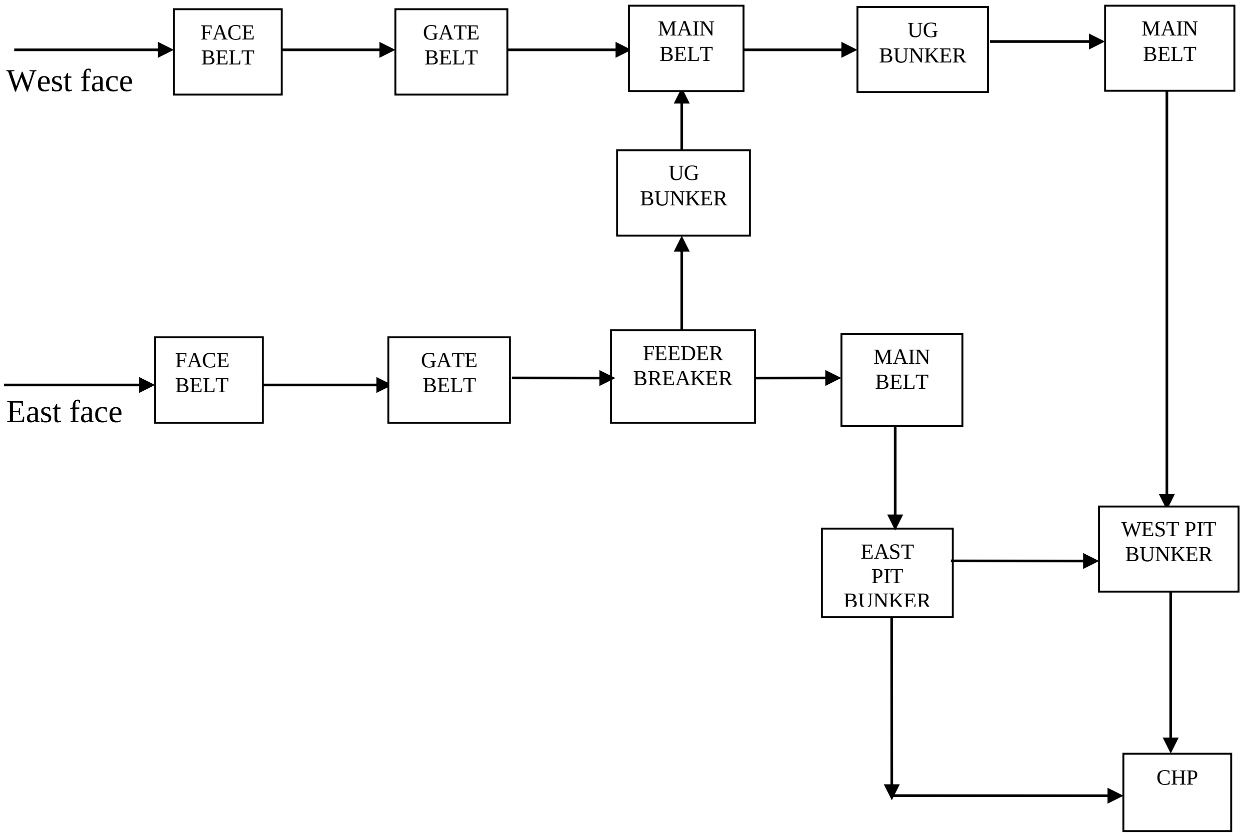


Figure 3.3: Production layout of Churcha (RO) mine

3.2.4 Conveyor Belt Detail of Churcha (RO) Mine

The conveyor belt is broadly utilized as a part of the production line of mines. It is the way of the material flow for mining industry and underground mines transportation of coal & materials are very difficult & challenging task for the mining industry. Conveyor belt system is the technic to transport of coal & material for the mining industry. In Churcha (RO) mine, there is seven main conveyor belt used for effective transportation of coal from the mines. In that, the main focus is on the conveyor belt system, because they take the majority of operational work in the mine, and they have high initial and operational cost. Table 3.3 present the detail of main conveyor system is classified regarding length and width.

Table 3.3: Conveyor belt detail of Churcha (RO) mine

SL	Conveyor Belt No	Width (mm)	Length (m)
1	C1	1200	410
2	C2	1200	510

3	C3	1200	620
4	C4	1200	580
5	C5	1200	370
6	C6	1200	180
7	C7	1200	840

All the main conveyor belt subsystem is in series and the analyses of reliability, availability and maintainability are done for seven conveyor subsystem in the main production line. Figure 3.4 presents the conveyor subsystem in the main production line in Churcha (RO) mine.

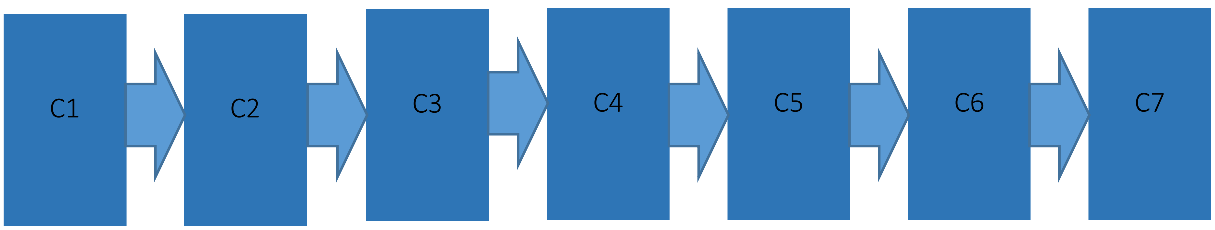


Figure 3.4: Main Conveyor system in series

This data set given below in the form of TBF and TTR of the conveyor belt. There is seven main conveyor belt used for effective transportation of coal from the mines. In that, the main focus is on the conveyor belt, because they take the majority of operational work in mine. And they have high initial and operational cost. For efficient work in a mining operation, those machinery should give their maximum performance.

3.3 Research Methodology

The research purpose for any investigator is related to what kind of a result of research work will obtain. The investigator can try to explore, describe, explain, understand, predict, change, evaluate and assess impacts [24]. The primary objective of this study is to analyze the reliability, availability, and maintainability of the main conveyor system of the Churcha (RO) mine.
Reliability in a qualitative form is usually not practical for an engineer. Therefore, the reliability should be analyzed in a quantitative method to give some practical impact. The flowchart of the research work is shown in Figure 3.5. The works involves the following steps for reliability, availability, and maintainability (RAM) analyses:

- Identification of system and data collection
- Data analysis
- Data evaluation
- TTF and TTR data analysis
- RAM analysis

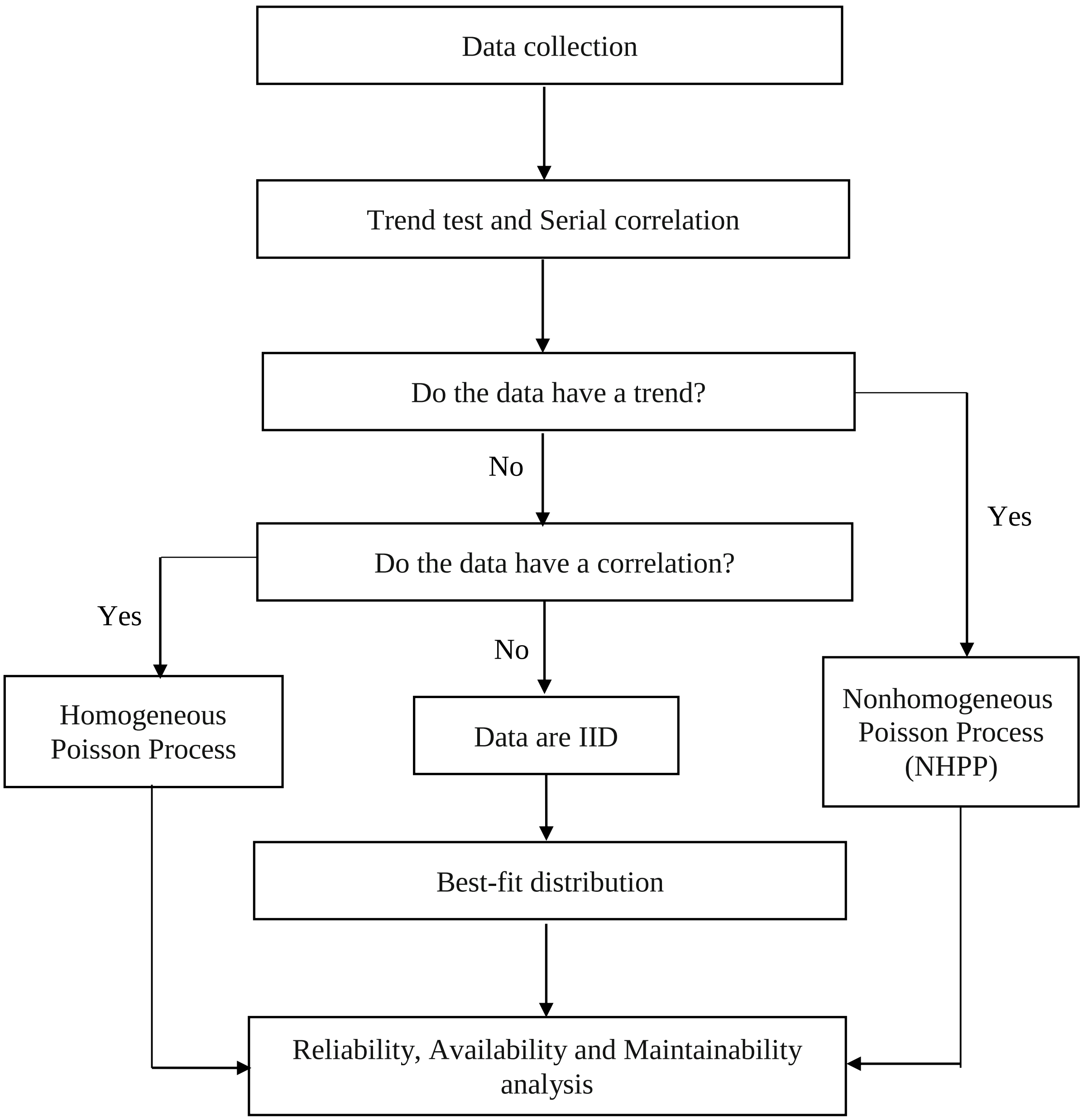


Figure 3.5: Methodology for reliability and maintainability analysis

3.4 Data collection

The first step of working methodology is the data collection. The failure and repairable data of the defined system are continuously recorded for the analyses. The present study monitor the failure and repair time data of the main conveyor system were monitored in the Churcha (RO) mine. The data for each of the seven subsystems of the main conveyor system in Churcha (RO) mine were recorded separately.

For the RAM analysis, the TBF and TTR data are determined. The data is quantitative and based on raw data collected over a period of six months. The data collected is from daily downtime reports and maintenance records, such as work orders created by maintenance personnel. The raw data used in the present study is secondary data. It means that someone else besides the analyzer collects it for some general purpose. In this case, that general purpose of the data collection is for production and maintenance information. After collection, the processing (sorting and classification) of raw data is performed. After processing, the data is in a format that is usable for statistical analysis. The analysis deals with a repairable system, and the data collected is failure and repair times of the subsystems compiling the entire system.

3.5 Data evaluation

It describes the approach needed for evaluation of the collected data to select appropriate probability and statistical analyses techniques. The main assumption of the data is that the collected data are independent and identically distributed (IID). This assumption needs verification by appropriate statistical tests such as the trend and serial correlation test. These are explained below.

3.5.1 IID assumption

The assumption that the data sets are IID implies that probability distributions can be used to model the subsystems. If the data sets do not fulfill the IID requirement, and probability distributions are used for modeling, then the results and the conclusions of the analysis can be totally wrong [26]. The assumption that the data sets are independent means that one failure is not dependent on the previous one, which implies that the parameters of the chosen distribution do not change with time. The assumption that the data sets are identical means that the different data points follow the same distribution.

A simple illustrative example is a cone toss, where one toss is never dependent on the previous one, neither is the probability of tossing heads or tails changing with time (the probability is the same whether it is the 1st toss or the 100th toss). For that reason, the probability distribution do is time-independent, and the different tosses are identical distributed.

Non-homogeneous processes, like the Poisson process, can be used for modeling, instead of probability distributions, in the case where the IID requirement is not fulfilled [26]. The trend test can verify the independent assumption, either analytically or graphically. While the serial correlation test can verify the identical assumption, either analytically or graphically. In this study, the IID assumption will be checked graphically by the two mentioned tests.

3.5.2 Trend test

In the trend test, the cumulative TBF or TTR is plotted against the cumulative failure number or repair number. If a line drawn through the data points either resembles a concave upwards or concave downwards trend in the data, the system is respectively an improving or deteriorating system. However, if the line drawn through the data points is approximately a straight line, then the data is free from the trend, which implies that the data set is identically distributed [26].

3.5.3 Serial correlation test

In the serial correlation test, the $(i\text{-}1)^{th}$ TBF/TTR is plotted against the i^{th} TBF/TTR. If the data points are randomly scattered without any clear pattern, it implies a data set free from serial correlation, which again implies that the data points in the data set are independent of each other [26].

3.6 Data analysis

This section describes the methods used for data analysis. The system is modeled by TBF and TTR data analysis. The best-fit probability distributions are identified by a goodness-of-fit test and parameters for the best fit distribution estimated through the maximum likelihood estimation method.

3.6.1 TBF and TTR data analysis

For a repairable system, the analysis is concerned with modeling both the time it takes from a performed repair action (or restoration) to the next system failure (life of the system) and the time it takes to restore the system (repair of the system) back to operating state. The main goal of the TBF and TTR data analysis is to model the failure and repair processes of the different subsystems. It is done by fitting a probability distribution that best represent the failure data, and fitting a distribution that best represent the repair data, and estimating parameters to fit the distributions to the different data sets. The mathematical expressions of various probability distributions on common used life and repair distributions are explained in Chapter 2.

It is common to assess the time between failures for analysis of repairable systems. In this case, the downtime duration, and more specific, the repair duration, is considerably lower than the uptime duration. For that reason, the analysis considers the time from restoration to system failure, denoted TBF, and the significant smaller repair duration denoted TTR.

3.6.2 Goodness-of-fit test

To select a suitable probability distribution function, its goodness-of-fit should be identified by the appropriate test. There exist several goodness-of-fit tests suited for different conditions. Some of the most used are the p-value test, the Chi-squared test, Kolmogorov-Smirnov test and Anderson-Darling test [27]. The principle behind goodness-of-fit tests is to see how far the chosen distribution is matched with the actual data set, or in other words, how well the chosen distribution represents the observed distribution. One goodness-of-fit test often used in RAM analysis is the Kolmogorov-Smirnov (K-S) test. The original K-S test is only applicable for distributions with known parameters. In case the parameters are calculated based on the data set itself, a modified K-S test can be used. For more information on the modified K-S test used in the case study. After fitting distributions to the data sets the parameters of the specific distributions, it needs to be estimated. There are several methods available, like the Rank Regression method, the Maximum Likelihood Estimation (MLE) and the Bayesian Estimation method. In the present study, the MLE method will be used. The reliability software easy-fit was used to perform both the goodness-of-fit test and the parameter estimation by MLE method.

3.7 Failure and Repair Data of Main Conveyor System

The failure and repair data of seven subsystems or seven conveyor belts (C1, C2, C3, C4, C5, C6 and C7) are shown in Table 3.4. The data are taken from the Churcha (RO) mine for the six-month duration (July 2015 to December 2015).

Table 3.4: Failure and Repair data of various subsystem of main conveyor system

Conveyor Belt C1								
	Date of failure	**Date of repair**		**Date of failure**	**Date of repair**		**Date of failure**	**Date of repair**
1	7/3/15 10:45	7/3/15 12:15	19	9/1/15 11:30	9/1/15 13:15	37	11/5/15 14:35	11/5/15 15:45
2	7/7/15 19:30	7/7/15 20:15	20	9/4/15 7:20	9/4/15 10:45	38	11/9/15 11:15	11/9/15 12:00
3	7/9/15 7:30	7/9/15 10:45	21	9/6/15 14:45	9/6/15 15:25	39	11/15/15 10:00	11/15/15 11:25
4	7/13/15 22:15	7/14/15 6:30	22	9/10/15 5:10	9/10/15 6:30	40	11/17/15 23:25	11/18/15 3:30
5	7/18/15 11:25	7/18/15 12:45	23	9/13/15 20:15	9/13/15 21:30	41	11/21/15 17:30	11/21/15 19:25
6	7/21/15 7:25	7/21/15 8:30	24	9/18/15 19:30	9/18/15 20:30	42	11/26/15 5:45	11/26/15 6:20
7	7/22/15 17:55	7/22/15 20:15	25	9/19/15 10:30	9/19/15 17:50	43	11/27/15 18:30	11/27/15 19:00
8	7/26/15 10:25	7/26/15 13:35	26	9/25/15 19:25	9/25/15 20:15	44	11/30/15 10:10	11/30/15 11:00
9	7/29/15 6:20	7/29/15 7:45	27	9/30/15 6:30	9/30/15 7:30	45	12/1/15 13:00	12/1/15 14:30
10	8/2/15 5:20	8/2/15 7:15	28	10/3/15 14:35	10/3/15 15:40	46	12/3/15 7:15	12/3/15 7:45
11	8/5/15 10:15	8/5/15 11:25	29	10/5/15 6:30	10/5/15 7:15	47	12/8/15 10:25	12/8/15 14:25
12	8/7/15 22:20	8/8/15 2:45	30	10/9/15 7:45	10/9/15 8:30	48	12/10/15 19:10	12/10/15 21:40
13	8/12/15 6:30	8/12/15 7:15	31	10/16/15 15:25	10/16/15 20:40	49	12/15/15 14:25	12/15/15 15:30
14	8/14/15 18:20	8/14/15 20:30	32	10/18/15 18:35	10/18/15 19:40	50	12/18/15 17:00	12/19/15 10:30
15	8/18/15 12:45	8/18/15 13:50	33	10/21/15 13:30	10/21/15 14:00	51	12/23/15 11:20	12/23/15 11:45
16	8/21/15 22:35	8/22/15 1:30	34	10/25/15 20:00	10/25/15 22:15	52	12/26/15 1:25	12/26/15 2:00
17	8/25/15 7:45	8/25/15 10:25	35	10/29/15 3:15	10/29/15 7:30	53	12/29/15 17:50	12/30/15 12:40
18	8/27/15 13:20	8/27/15 14:50	36	11/4/15 6:15	11/4/15 7:00			
Conveyor Belt C2								
1	7/1/15 11:30	7/1/15 13:20	19	8/30/15 5:35	8/30/15 6:50	37	11/1/15 12:25	11/1/15 14:25
2	7/4/15 6:30	7/4/15 7:15	20	9/3/15 6:15	9/3/15 7:00	38	11/4/15 14:45	11/4/15 15:55
3	7/5/15 19:30	7/5/15 20:35	21	9/7/15 11:15	9/7/15 12:45	39	11/7/15 11:15	11/7/15 12:45
4	7/9/15 10:45	7/9/15 11:50	22	9/10/15 14:35	9/10/15 15:50	40	11/12/15 6:45	11/12/15 8:15
5	7/13/15 19:30	7/13/15 20:40	23	9/14/15 5:45	9/14/15 6:40	41	11/16/15 19:15	11/16/15 21:00
6	7/18/15 3:30	7/18/15 6:15	24	9/16/15 17:55	9/16/15 18:40	42	11/21/15 12:45	11/21/15 13:30
7	7/20/15 5:30	7/20/15 7:50	25	9/18/15 10:00	9/18/15 11:15	43	11/24/15 4:30	11/24/15 6:00
8	7/24/15 22:10	7/25/15 2:35	26	9/22/15 23:30	9/23/15 1:30	44	11/29/15 18:30	11/29/15 20:45
9	7/28/15 6:30	7/28/15 7:45	27	9/26/15 5:15	9/26/15 7:00	45	12/3/15 16:15	12/3/15 16:40
10	8/1/15 14:35	8/1/15 15:30	28	9/30/15 14:30	9/30/15 16:15	46	12/4/15 19:10	12/4/15 21:40

11	8/5/15 7:20	8/5/15 10:45	29	10/1/15 13:00	10/1/15 14:30	47	12/8/15 14:00	12/8/15 14:30
12	8/7/15 11:30	8/7/15 12:50	30	10/5/15 19:10	10/5/15 21:30	48	12/13/15 6:45	12/13/15 7:30
13	8/10/15 18:35	8/10/15 20:30	31	10/7/15 7:35	10/7/15 9:35	49	12/18/15 10:30	12/18/15 12:40
14	8/14/15 10:30	8/14/15 11:30	32	10/11/15 11:20	10/11/15 13:25	50	12/22/15 9:30	12/22/15 10:30
15	8/16/15 20:15	8/16/15 21:30	33	10/16/15 5:25	10/16/15 10:25	51	12/26/15 8:30	12/26/15 12:30
16	8/21/15 9:30	8/21/15 11:20	34	10/19/15 14:30	10/19/15 15:50	52	12/31/15 6:45	12/31/15 7:15
17	8/24/15 12:35	8/24/15 14:45	35	10/23/15 6:15	10/23/15 7:35			
18	8/26/15 17:30	8/26/15 19:15	36	10/27/15 20:30	10/27/15 21:30			
Conveyor Belt C3								
1	7/4/15 17:20	7/4/15 18:00	14	9/9/15 9:45	9/9/15 10:15	27	11/12/15 20:30	11/12/15 22:15
2	7/10/15 6:30	7/10/15 8:00	15	9/14/15 5:30	9/14/15 8:00	28	11/13/15 9:50	11/13/15 10:30
3	7/14/15 20:35	7/14/15 21:15	16	9/20/15 18:35	9/20/15 19:20	29	11/19/15 12:15	11/19/15 13:35
4	7/19/15 10:50	7/19/15 11:45	17	9/23/15 20:20	9/23/15 20:50	30	11/26/15 10:40	11/26/15 11:45
5	7/25/15 18:35	7/25/15 19:15	18	9/29/15 3:35	9/29/15 4:20	31	12/1/15 13:15	12/1/15 14:25
6	7/29/15 9:45	7/29/15 10:30	19	10/4/15 17:45	10/4/15 18:30	32	12/7/15 7:20	12/7/15 10:30
7	8/4/15 11:30	8/4/15 13:30	20	10/7/15 5:45	10/7/15 6:15	33	12/11/15 14:35	12/11/15 16:00
8	8/11/15 7:20	8/11/15 12:25	21	10/12/15 11:45	10/12/15 13:30	34	12/18/15 20:00	12/18/15 20:45
9	8/15/15 19:20	8/15/15 20:40	22	10/18/15 19:15	10/18/15 20:25	35	12/22/15 9:15	12/22/15 10:30
10	8/21/15 4:50	8/21/15 6:00	23	10/24/15 3:40	10/24/15 5:00	36	12/25/15 10:10	12/25/15 11:00
11	8/27/15 22:30	8/28/15 3:15	24	10/27/15 14:35	10/27/15 15:30	37	12/30/15 6:30	12/30/15 7:30
12	9/3/15 10:45	9/3/15 12:15	25	11/1/15 16:45	11/1/15 19:30			
13	9/7/15 17:50	9/7/15 18:30	26	11/6/15 5:15	11/6/15 5:45			
Conveyor Belt C4								
1	7/1/15 12:50	7/1/15 13:45	20	8/23/15 10:25	8/23/15 11:00	39	10/26/15 16:10	10/26/15 17:15
2	7/3/15 6:40	7/3/15 7:30	21	8/25/15 18:20	8/25/15 19:00	40	10/29/15 10:30	10/29/15 11:00
3	7/4/15 22:15	7/5/15 10:15	22	8/29/15 17:15	8/29/15 17:45	41	11/2/15 6:45	11/2/15 7:30
4	7/8/15 18:35	7/8/15 19:15	23	9/3/15 7:20	9/3/15 8:00	42	11/7/15 4:40	11/7/15 5:30
5	7/10/15 7:15	7/10/15 8:30	24	9/5/15 10:30	9/5/15 11:45	43	11/10/15 12:50	11/10/15 14:40
6	7/14/15 20:30	7/14/15 21:45	25	9/8/15 3:30	9/8/15 5:30	44	11/15/15 12:00	11/15/15 12:30
7	7/17/15 14:30	7/17/15 15:50	26	9/13/15 17:00	9/13/15 17:45	45	11/17/15 22:50	11/18/15 2:15
8	7/18/15 16:20	7/18/15 17:35	27	9/15/15 12:15	9/15/15 13:30	46	11/20/15 18:25	11/20/15 19:00
9	7/21/15 10:30	7/21/15 11:25	28	9/18/15 14:50	9/18/15 17:30	47	11/26/15 13:35	11/26/15 14:15
10	7/25/15 8:15	7/25/15 10:45	29	9/20/15 4:30	9/20/15 5:00	48	11/30/15 9:45	11/30/15 11:30
11	7/28/15 3:45	7/28/15 5:00	30	9/24/15 18:45	9/24/15 19:50	49	12/5/15 11:15	12/5/15 12:00
12	8/1/15 13:30	8/1/15 14:15	31	9/28/15 11:45	9/28/15 12:50	50	12/7/15 16:25	12/7/15 17:20
13	8/4/15 17:25	8/4/15 19:30	32	10/1/15 15:25	10/1/15 16:30	51	12/9/15 6:40	12/9/15 10:45
14	8/6/15 18:45	8/6/15 19:15	33	10/4/15 9:25	10/4/15 10:15	52	12/11/15 9:30	12/11/15 10:40
15	8/10/15 10:10	8/10/15 12:25	34	10/8/15 6:30	10/8/15 7:15	53	12/16/15 20:20	12/16/15 21:30
16	8/10/15 18:30	8/10/15 20:50	35	10/13/15 20:10	10/13/15 21:30	54	12/20/15 11:20	12/20/15 15:25
17	8/12/15 3:15	8/12/15 4:30	36	10/16/15 17:45	10/16/15 19:00	55	12/26/15 12:35	12/26/15 13:25
18	8/15/15 20:15	8/15/15 20:45	37	10/20/15 4:20	10/20/15 5:25	56	12/29/15 18:50	12/29/15 20:00

19	8/19/15 11:40	8/19/15 12:35	38	10/22/15 14:15	10/22/15 20:55			
Conveyor Belt C5								
1	7/4/15 14:30	7/4/15 15:45	12	9/11/15 14:45	9/11/15 15:30	23	11/9/15 4:30	11/9/15 9:25
2	7/11/15 5:35	7/11/15 6:40	13	9/18/15 9:50	9/18/15 10:40	24	11/17/15 14:35	11/17/15 15:15
3	7/15/15 12:15	7/15/15 14:20	14	9/22/15 18:20	9/22/15 22:30	25	11/20/15 11:15	11/20/15 11:45
4	7/21/15 18:25	7/21/15 19:00	15	9/28/15 11:45	9/28/15 13:30	26	11/28/15 10:40	11/28/15 11:30
5	7/28/15 10:35	7/28/15 12:10	16	10/3/15 15:30	10/3/15 17:20	27	12/4/15 15:35	12/4/15 16:40
6	8/2/15 7:45	8/2/15 9:30	17	10/5/15 12:00	10/5/15 13:25	28	12/10/15 9:15	12/10/15 10:30
7	8/9/15 15:30	8/9/15 16:45	18	10/13/15 21:20	10/13/15 22:00	29	12/12/15 20:25	12/12/15 21:15
8	8/16/15 17:10	8/16/15 17:50	19	10/19/15 13:15	10/19/15 14:30	30	12/19/15 3:50	12/19/15 4:25
9	8/25/15 22:20	8/25/15 23:15	20	10/25/15 11:30	10/25/15 12:15	31	12/20/15 10:40	12/20/15 11:25
10	8/27/15 4:35	8/27/15 5:45	21	10/28/15 9:25	10/28/15 10:30	32	12/27/15 16:35	12/27/15 17:45
11	9/3/15 11:30	9/3/15 13:30	22	11/2/15 22:00	11/2/15 22:30			
Conveyor Belt C6								
1	7/3/15 6:40	7/3/15 7:40	21	8/23/15 10:25	8/23/15 11:30	41	10/26/15 16:10	10/26/15 17:15
2	7/4/15 22:15	7/5/15 10:15	22	8/25/15 18:20	8/25/15 19:00	42	10/29/15 10:30	10/29/15 11:00
3	7/6/15 10:25	7/6/15 12:15	23	8/29/15 17:20	8/29/15 17:45	43	11/2/15 6:25	11/2/15 7:30
4	7/8/15 18:25	7/8/15 19:15	24	9/3/15 7:20	9/3/15 8:00	44	11/7/15 4:40	11/7/15 5:30
5	7/10/15 7:15	7/10/15 9:30	25	9/5/15 10:30	9/5/15 11:45	45	11/10/15 12:50	11/10/15 14:40
6	7/14/15 20:30	7/14/15 21:45	26	9/8/15 3:30	9/8/15 5:30	46	11/15/15 12:00	11/15/15 12:30
7	7/17/15 14:30	7/17/15 15:50	27	9/13/15 17:00	9/13/15 17:45	47	11/17/15 22:40	11/18/15 2:15
8	7/18/15 16:20	7/18/15 17:35	28	9/15/15 12:15	9/15/15 13:30	48	11/20/15 18:25	11/20/15 19:00
9	7/21/15 10:30	7/21/15 11:25	29	9/18/15 13:50	9/18/15 17:30	49	11/26/15 13:35	11/26/15 14:30
10	7/22/15 17:30	7/22/15 18:45	30	9/20/15 4:30	9/20/15 5:00	50	11/30/15 9:45	11/30/15 11:30
11	7/25/15 8:15	7/25/15 10:45	31	9/24/15 18:45	9/24/15 20:10	51	12/5/15 11:15	12/5/15 12:00
12	7/28/15 3:45	7/28/15 5:00	32	9/28/15 11:45	9/28/15 12:50	52	12/7/15 16:25	12/7/15 17:20
13	8/2/15 6:15	8/2/15 10:45	33	10/1/15 13:25	10/1/15 16:30	53	12/9/15 6:40	12/9/15 10:45
14	8/4/15 17:25	8/4/15 19:30	34	10/4/15 9:25	10/4/15 10:15	54	12/11/15 9:30	12/11/15 10:40
15	8/6/15 18:45	8/6/15 19:15	35	10/8/15 6:30	10/8/15 7:15	55	12/16/15 20:30	12/16/15 21:30
16	8/9/15 10:50	8/9/15 11:30	36	10/10/15 13:20	10/10/15 14:50	56	12/20/15 11:10	12/20/15 15:25
17	8/10/15 18:30	8/10/15 20:50	37	10/13/15 20:10	10/13/15 21:30	57	12/26/15 12:35	12/26/15 13:25
18	8/12/15 3:15	8/12/15 4:30	38	10/16/15 17:35	10/16/15 19:00	58	12/29/15 18:50	12/29/15 20:30
19	8/15/15 20:15	8/15/15 20:45	39	10/20/15 4:20	10/20/15 5:35			
20	8/19/15 11:40	8/19/15 12:35	40	10/22/15 14:15	10/22/15 20:55			
Conveyor Belt C7								
1	7/5/15 14:20	7/5/15 15:45	11	9/11/15 14:45	9/11/15 15:30	21	11/9/15 4:30	11/9/15 9:25
2	7/15/15 12:15	7/15/15 14:30	12	9/18/15 9:30	9/18/15 10:40	22	11/17/15 14:35	11/17/15 15:15
3	7/21/15 18:35	7/21/15 19:00	13	9/22/15 18:20	9/22/15 22:30	23	11/20/15 11:15	11/20/15 11:45
4	7/27/15 10:35	7/27/15 12:10	14	9/28/15 11:45	9/28/15 13:30	24	11/28/15 10:40	11/28/15 11:30
5	8/2/15 7:25	8/2/15 9:30	15	10/3/15 15:30	10/3/15 16:20	25	12/4/15 15:35	12/4/15 16:40
6	8/9/15 15:30	8/9/15 16:45	16	10/5/15 12:00	10/5/15 13:35	26	12/10/15 9:15	12/10/15 10:30

7	8/16/15 17:10	8/16/15 17:50	17	10/13/15 21:20	10/13/15 22:00	27	12/19/15 3:50	12/19/15 4:25
8	8/25/15 11:00	8/25/15 12:15	18	10/19/15 13:15	10/19/15 17:30	28	12/20/15 10:40	12/20/15 11:35
9	8/27/15 3:35	8/27/15 6:45	19	10/25/15 11:30	10/25/15 12:15	29	12/27/15 16:25	12/27/15 17:45
10	9/3/15 11:30	9/3/15 13:30	20	11/2/15 22:00	11/2/15 22:30			

Chapter 4

Result and Discussion

4.1 Failure frequency of the Conveyor Belt

There is seven subsystems of the main conveyor system, and all the seven subsystems has different frequency of failure. The frequency of the failure is shown in Table 4.1. To get a clearer view of the frequency of failures of the subsystems, a bar chart is also produced. The bar chart is reported in Figure 4.1. Figure 4.1 clearly illustrates that the subsystem C6 is the most frequent failure subsystem. The subsystem C7 has the lowest frequency of failure, that is, 29-times in six-month duration.

Table 4.1: Failure frequency of the conveyor belt

Sl	Subsystem	frequency
1	C1	53
2	C2	52
3	C3	37
4	C4	56
5	C5	32
6	C6	58
7	C7	29

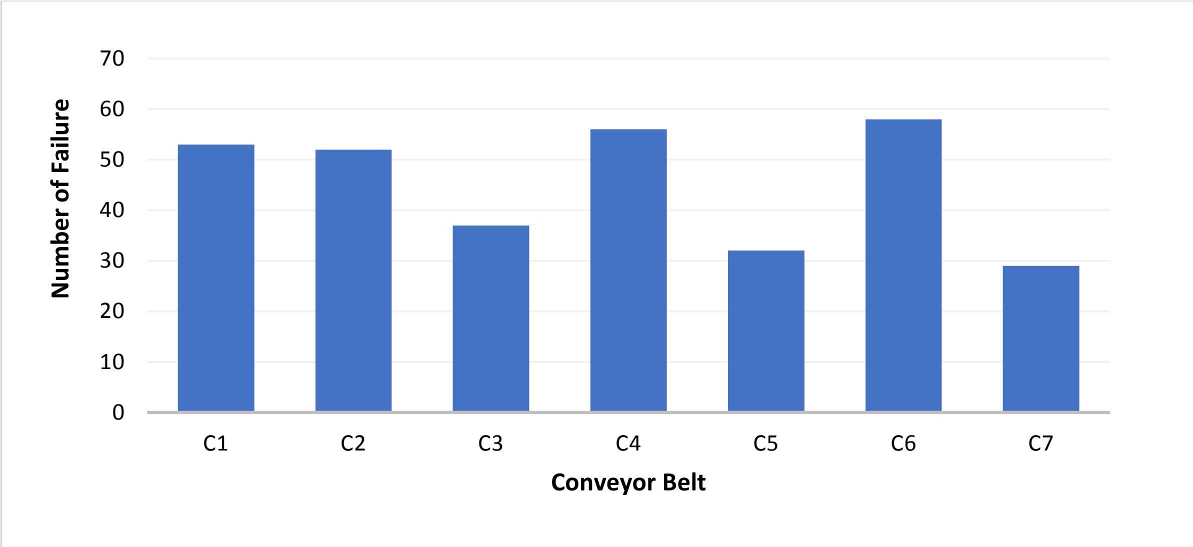


Figure 4.1: Bar diagram shows failure frequency of the subsystems

4.2 Determination of TBF, TTR, CTBF and CTTR

To verify the IID assumption of various subsystems, the TBFs and TTRs needs to be sorted and arranged sequentially to get the cumulative TBFs and cumulative TTRs. The TBF, TTR, CTBF, and CTTR for each of the subsystem (C1, C2, C3, C4, C5, C6 and C7) were calculated and produced in Table 4.2.

Table 4.2: TTF, TTR, CTBF, and CTTR for each subsystem

C1									
No	**TBF**	**TTR**	**CTBF**	**CTTR**	**No**	**TBF**	**TTR**	**CTBF**	**CTTR**
1	104.75	1.5	104.75	1.5	28	39.92	1.08	2248.09	61.32
2	36	0.75	140.75	2.25	29	97.25	0.75	2345.34	62.07
3	110.75	3.25	251.5	5.5	30	175.66	0.75	2521	62.82
4	109.17	8.25	360.67	13.75	31	51.17	5.25	2572.17	68.07
5	68	1.33	428.67	15.08	32	66.92	1.08	2639.09	69.15
6	30.5	1.08	459.17	16.16	33	102.5	0.5	2741.59	69.65
7	88.5	2.33	547.67	18.49	34	79.25	2.25	2820.84	71.9
8	67.92	3.17	615.59	21.66	35	147	4.25	2967.84	76.15
9	95	1.42	710.59	23.08	36	32.33	0.75	3000.17	76.9
10	76.92	1.92	787.51	25	37	92.66	1.17	3092.83	78.07

11	60.08	1.17	847.59	26.17	38	142.75	0.75	3235.58	78.82
12	104.17	4.42	951.76	30.59	39	61.42	1.42	3297	80.24
13	59.83	0.75	1011.59	31.34	40	90.08	4.08	3387.08	84.32
14	90.42	2.17	1102.01	33.51	41	108.25	1.92	3495.33	86.24
15	81.83	1.08	1183.84	34.59	42	36.75	0.58	3532.08	86.82
16	81.17	2.92	1265.01	37.51	43	63.66	0.5	3595.74	87.32
17	53.58	2.66	1318.59	40.17	44	26.83	0.83	3622.57	88.15
18	118.17	1.5	1436.76	41.67	45	42.25	1.5	3664.82	89.65
19	67.83	1.75	1504.59	43.42	46	123.17	0.5	3787.99	90.15
20	55.42	3.42	1560.01	46.84	47	56.75	4	3844.74	94.15
21	86.75	0.66	1646.76	47.5	48	115.25	2.5	3959.99	96.65
22	87.08	1.33	1733.84	48.83	49	74.58	1.08	4034.57	97.73
23	119.25	1.25	1853.09	50.08	50	114.33	17.5	4148.9	115.23
24	15	1	1868.09	51.08	51	62.08	0.42	4210.98	115.65
25	152.92	7.33	2021.01	58.41	52	88.42	0.58	4299.4	116.23
26	107.08	0.83	2128.09	59.24	53		18.83		135.06
27	80.08	1	2208.17	60.24					
C2									
1	67	1.83	67	1.83	27	105.25	1.75	2176.98	43.67
2	37	0.75	104	2.58	28	22.5	1.75	2199.48	45.42
3	87.25	1.08	191.25	3.66	29	102.17	1.5	2301.65	46.92
4	104.75	1.08	296	4.74	30	36.42	2.33	2338.07	49.25
5	104	1.17	400	5.91	31	99.75	2	2437.82	51.25
6	50	2.75	450	8.66	32	114.08	2.08	2551.9	53.33
7	112.66	2.33	562.66	10.99	33	81.08	5	2632.98	58.33
8	80.33	4.42	642.99	15.41	34	87.75	1.33	2720.73	59.66
9	104.08	1.25	747.07	16.66	35	110.25	1.33	2830.98	60.99
10	88.75	0.92	835.82	17.58	36	111.92	1	2942.9	61.99
11	52.17	3.42	887.99	21	37	74.33	2	3017.23	63.99
12	79.08	1.33	967.07	22.33	38	68.5	1.17	3085.73	65.16
13	87.92	1.92	1054.99	24.25	39	115.5	1.5	3201.23	66.66
14	57.75	1	1112.74	25.25	40	108.5	1.5	3309.73	68.16
15	109.25	1.25	1221.99	26.5	41	113.5	1.75	3423.23	69.91
16	75.08	1.83	1297.07	28.33	42	63.75	0.75	3486.98	70.66
17	52.92	2.17	1349.99	30.5	43	134	1.5	3620.98	72.16
18	84.08	1.75	1434.07	32.25	44	93.75	2.25	3714.73	74.41
19	96.66	1.25	1530.73	33.5	45	26.92	0.42	3741.65	74.83
20	101	0.75	1631.73	34.25	46	90.83	2.5	3832.48	77.33
21	75.33	1.5	1707.06	35.75	47	112.75	0.5	3945.23	77.83
22	87.17	1.25	1794.23	37	48	123.75	0.75	4068.98	78.58
23	60.17	0.92	1854.4	37.92	49	95	2.17	4163.98	80.75

24	30.08	0.75	1884.48	38.67	50	95	1	4258.98	81.75
25	109.5	1.25	1993.98	39.92	51	118.25	4	4377.23	85.75
26	77.75	2	2071.73	41.92	52		0.5		86.25
C3									
1	133.17	0.66	133.17	0.66	20	126	0.5	2394.41	27.89
2	110.08	1.5	243.25	2.16	21	151.5	1.75	2545.91	29.64
3	110.25	0.66	353.5	2.82	22	128.42	1.17	2674.33	30.81
4	151.75	0.92	505.25	3.74	23	82.92	1.33	2757.25	32.14
5	87.17	0.66	592.42	4.4	24	122.17	0.92	2879.42	33.06
6	145.75	0.75	738.17	5.15	25	108.5	2.75	2987.92	35.81
7	163.83	2	902	7.15	26	159.25	0.5	3147.17	36.31
8	108	5.08	1010	12.23	27	13.33	1.75	3160.5	38.06
9	129.5	1.33	1139.5	13.56	28	146.42	0.66	3306.92	38.72
10	161.66	1.17	1301.16	14.73	29	166.42	1.33	3473.34	40.05
11	156.25	4.75	1457.41	19.48	30	122.58	1.08	3595.92	41.13
12	103.08	1.5	1560.49	20.98	31	138.08	1.17	3734	42.3
13	39.92	0.66	1600.41	21.64	32	103.25	3.17	3837.25	45.47
14	115.75	0.5	1716.16	22.14	33	173.42	1.42	4010.67	46.89
15	157.08	2.5	1873.24	24.64	34	85.25	0.75	4095.92	47.64
16	73.75	0.75	1946.99	25.39	35	72.92	1.25	4168.84	48.89
17	127.25	0.5	2074.24	25.89	36	116.33	0.83	4285.17	49.72
18	134.17	0.75	2208.41	26.64	37		1		50.72
19	60	0.75	2268.41	27.39					
C4									
1	41.83	0.92	41.83	0.92	29	110.25	0.5	2045.9	45.55
2	39.58	0.83	81.41	1.75	30	89	1.08	2134.9	46.63
3	92.33	12	173.74	13.75	31	75.66	1.08	2210.56	47.71
4	36.66	0.66	210.4	14.41	32	66	1.08	2276.56	48.79
5	109.25	1.25	319.65	15.66	33	93.08	0.83	2369.64	49.62
6	66	1.25	385.65	16.91	34	133.66	0.75	2503.3	50.37
7	25.83	1.33	411.48	18.24	35	69.58	1.33	2572.88	51.7
8	66.17	1.25	477.65	19.49	36	82.58	1.25	2655.46	52.95
9	93.75	0.92	571.4	20.41	37	57.92	1.08	2713.38	54.03
10	67.5	2.5	638.9	22.91	38	97.92	6.66	2811.3	60.69
11	105.75	1.25	744.65	24.16	39	66.33	1.08	2877.63	61.77
12	75.92	0.75	820.57	24.91	40	92.25	0.5	2969.88	62.27
13	49.33	2.08	869.9	26.99	41	117.92	0.75	3087.8	63.02
14	87.42	0.5	957.32	27.49	42	80.17	0.83	3167.97	63.85
15	8.33	2.25	965.65	29.74	43	119.17	1.83	3287.14	65.68
16	32.75	2.33	998.4	32.07	44	58.83	0.5	3345.97	66.18
17	89	1.25	1087.4	33.32	45	67.58	3.42	3413.55	69.6

18	87.42	0.5	1174.82	33.82	46	139.17	0.58	3552.72	70.18
19	94.75	0.92	1269.57	34.74	47	92.17	0.66	3644.89	70.84
20	55.92	0.58	1325.49	35.32	48	121.5	1.75	3766.39	72.59
21	94.92	0.66	1420.41	35.98	49	53.17	0.75	3819.56	73.34
22	110.08	0.5	1530.49	36.48	50	38.25	0.92	3857.81	74.26
23	51.17	0.66	1581.66	37.14	51	50.83	4.08	3908.64	78.34
24	65	1.25	1646.66	38.39	52	130.83	1.17	4039.47	79.51
25	133.5	2	1780.16	40.39	53	87	1.17	4126.47	80.68
26	43.25	0.75	1823.41	41.14	54	145.25	4.08	4271.72	84.76
27	74.58	1.25	1897.99	42.39	55	78.25	0.83	4349.97	85.59
28	37.66	2.66	1935.65	45.05	56		1.17		86.76
C5									
1	159.08	1.25	159.08	1.25	17	201.33	1.416	2430.82	25.078
2	102.66	1.08	261.74	2.33	18	135.92	0.66	2566.74	25.744
3	150.16	2.083	411.915	4.416	19	142.25	1.25	2708.99	26.994
4	160.16	0.58	572.08	4.99	20	69.91	0.66	2778.91	27.66
5	117.16	1.583	689.247	6.582	21	132.58	1.083	2911.49	28.743
6	175.75	1.75	864.99	8.332	22	150.50	0.50	3061.99	29.24
7	169.66	1.25	1034.66	9.58	23	202.08	4.92	3264.07	34.16
8	221.16	0.666	1255.82	10.248	24	68.666	0.666	3332.74	34.825
9	30.25	0.916	1286.07	11.164	25	191.41	0.5	3524.15	35.325
10	174.91	1.166	1460.99	12.33	26	148.91	0.833	3673.07	36.158
11	195.25	2	1656.24	14.33	27	137.66	1.083	3810.73	37.241
12	163.08	0.75	1819.32	15.08	28	59.166	1.25	3869.90	38.491
13	104.5	0.833	1923.82	15.913	29	151.41	0.833	4021.32	39.324
14	137.41	4.166	2061.24	20.079	30	30.833	0.583	4052.15	39.907
15	123.75	1.75	2184.99	21.829	31	173.91	0.75	4226.07	40.657
16	44.5	1.833	2229.49	23.662	32		1.166		41.823
C6									
1	39.58	1	39.58	1	30	110.25	0.5	2004.07	52.66
2	36.16	12	75.75	13	31	89	1.41	2093.07	54.07
3	56	1.83	131.74	14.83	32	73.66	1.08	2166.74	55.16
4	36.83	0.83	168.58	15.66	33	68	3.08	2234.74	58.24
5	109.25	2.25	277.83	17.91	34	93.08	0.83	2327.82	59.07
6	66	1.25	343.83	19.16	35	54.83	0.75	2382.65	59.82
7	25.83	1.33	369.66	20.49	36	78.83	1.5	2461.49	61.32
8	66.16	1.25	435.83	21.74	37	69.41	1.33	2530.90	62.65
9	31	0.91	466.83	22.66	38	82.75	1.41	2613.65	64.07
10	62.75	1.25	529.58	23.91	39	57.91	1.25	2671.57	65.32
11	67.50	2.5	597.08	26.41	40	97.91	6.66	2769.48	71.99
12	122.5	1.25	719.58	27.66	41	66.33	1.08	2835.82	73.07

13	59.16	4.5	778.74	32.16	42	91.91	0.5	2927.73	73.57
14	49.33	2.08	828.08	34.25	43	118.25	1.08	3045.98	74.65
15	64.08	0.5	892.16	34.74	44	80.16	0.83	3126.15	75.48
16	31.66	0.66	923.82	35.41	45	119.16	1.83	3245.32	77.32
17	32.75	2.33	956.57	37.74	46	58.66	0.5	3303.98	77.82
18	89	1.25	1045.57	38.99	47	67.75	3.58	3371.73	81.40
19	87.41	0.5	1132.99	39.49	48	139.16	0.58	3510.90	81.98
20	94.75	0.91	1227.74	40.41	49	92.16	0.91	3603.06	82.90
21	55.91	1.08	1283.66	41.49	50	121.5	1.75	3724.56	84.65
22	95	0.66	1378.66	42.16	51	53.16	0.75	3777.73	85.40
23	110	0.41	1488.66	42.57	52	38.25	0.91	3815.98	86.32
24	51.16	0.66	1539.82	43.24	53	50.83	4.08	3866.81	90.40
25	65	1.25	1604.82	44.49	54	131	1.16	3997.81	91.56
26	133.5	2	1738.32	46.49	55	86.66	1	4084.48	92.56
27	43.25	0.75	1781.57	47.24	56	145.41	4.25	4229.89	96.81
28	73.58	1.25	1855.16	48.49	57	78.25	0.83	4308.14	97.65
29	38.66	3.66	1893.82	52.16	58		1.66		99.31
C7									
1	237.91	1.41	237.91	1.42	16	201.33	1.58	2406.99	26.33
2	150.33	2.25	388.25	3.66	17	135.91	0.66	2542.91	26.99
3	136	0.42	524.25	4.08	18	142.25	4.25	2685.16	31.24
4	140.83	1.58	665.08	5.66	19	202.5	0.75	2887.66	31.99
5	176.08	2.083	841.16	7.74	20	150.5	0.5	3038.16	32.49
6	169.66	1.25	1010.83	8.99	21	202.08	4.916	3240.24	37.41
7	209.83	0.66	1220.66	9.66	22	68.66	0.66	3308.91	38.07
8	40.58	1.25	1261.24	10.91	23	191.41	0.5	3500.32	38.57
9	175.91	3.16	1437.16	14.08	24	148.91	0.83	3649.24	39.41
10	195.25	2	1632.41	16.08	25	137.66	1.08	3786.90	40.49
11	162.75	0.75	1795.16	16.83	26	210.58	1.25	3997.49	41.74
12	104.83	1.16	1899.99	17.99	27	30.83	0.58	4028.32	42.32
13	137.41	4.16	2037.41	22.16	28	173.75	0.91	4202.07	43.24
14	123.75	1.75	2161.16	23.91	29		1.33		44.57
15	44.5	0.83	2205.66	24.74					

4.3 Serial Correlation and Trend Tests for TBF and TTR Data

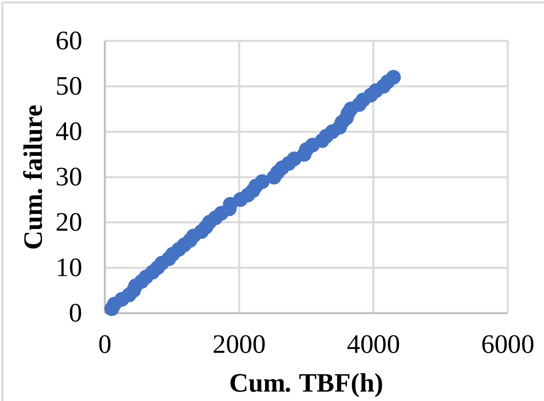
The trend test for the present study has been performed graphically. It is however possible to use an analytic method for investigating the trend of the data. Before fitting the data, it is important to check whether the data has a trend, i.e., if the rate of failures for the system/component is increasing, decreasing or constant. We can observe the trend of the failure data by plotting the cumulative time between failure and number of failure. If the trend exists, the line will concave upwards, suggesting an improving system. If the line is concaving downwards, it suggests a system that is deteriorating. If the line is linear, one can be sure that there is no trend in the data.

The objective of the serial correlation tests is to check the relationship between two variables. The scatter plots between the two variables (TBFi and TBFi-1) exhibits the correlation between the two variables.

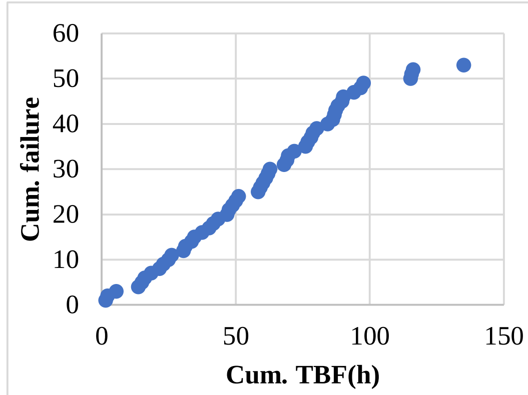
Figure 4.2(a) and Figure 4.2 (b) represents the trend tests TBF and TTR data of subsystem C1 respectively. Similarly, Figure 4.2(c) and Figure 4.2 (d) represent the scatter plots of TBF and TTR data of subsystem C1 respectively. The plot between the cumulative time between failure and number of failure for TBF and TTR of subsystem C1 shows that the line is linear. This indicates that there is no trend in the data. Similarly, the scatter plot between the two variables (TBFi and TBFi-1) shows that the data are widely scattered, and thus there is no correlation exists between the data of two consecutive failures. This is validating the assumptions of IID of TBF and TTR.

Similarly, we have conducted the trend test and correlation test for all other subsystems. These are shown in Figure 4.3, Figure 4.4, Figure 4.5, Figure 4.6, Figure 4.7, and figure 4.8 respectively for subsystem C2, C3, C4, C5, C6, and C7.

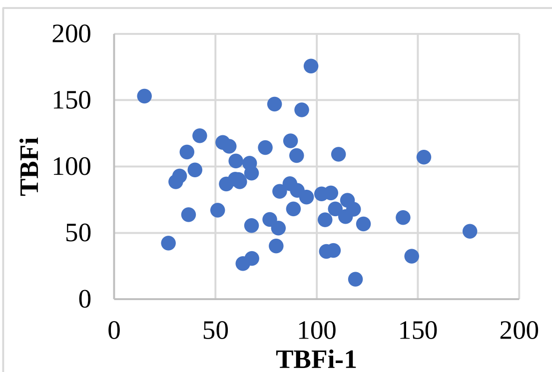
From the analyses, it was observed that there was no trend exist between the TBF and TTR with the number of failure in each case. It was also found that the TBF_i and TBF_{i-1} data follows IID assumptions.



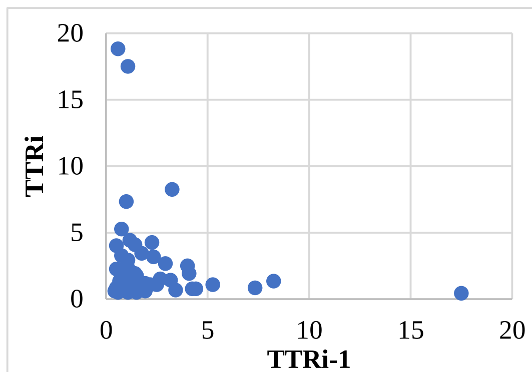
(a) Trend Test for TBF



(b) Trend Test for TTR

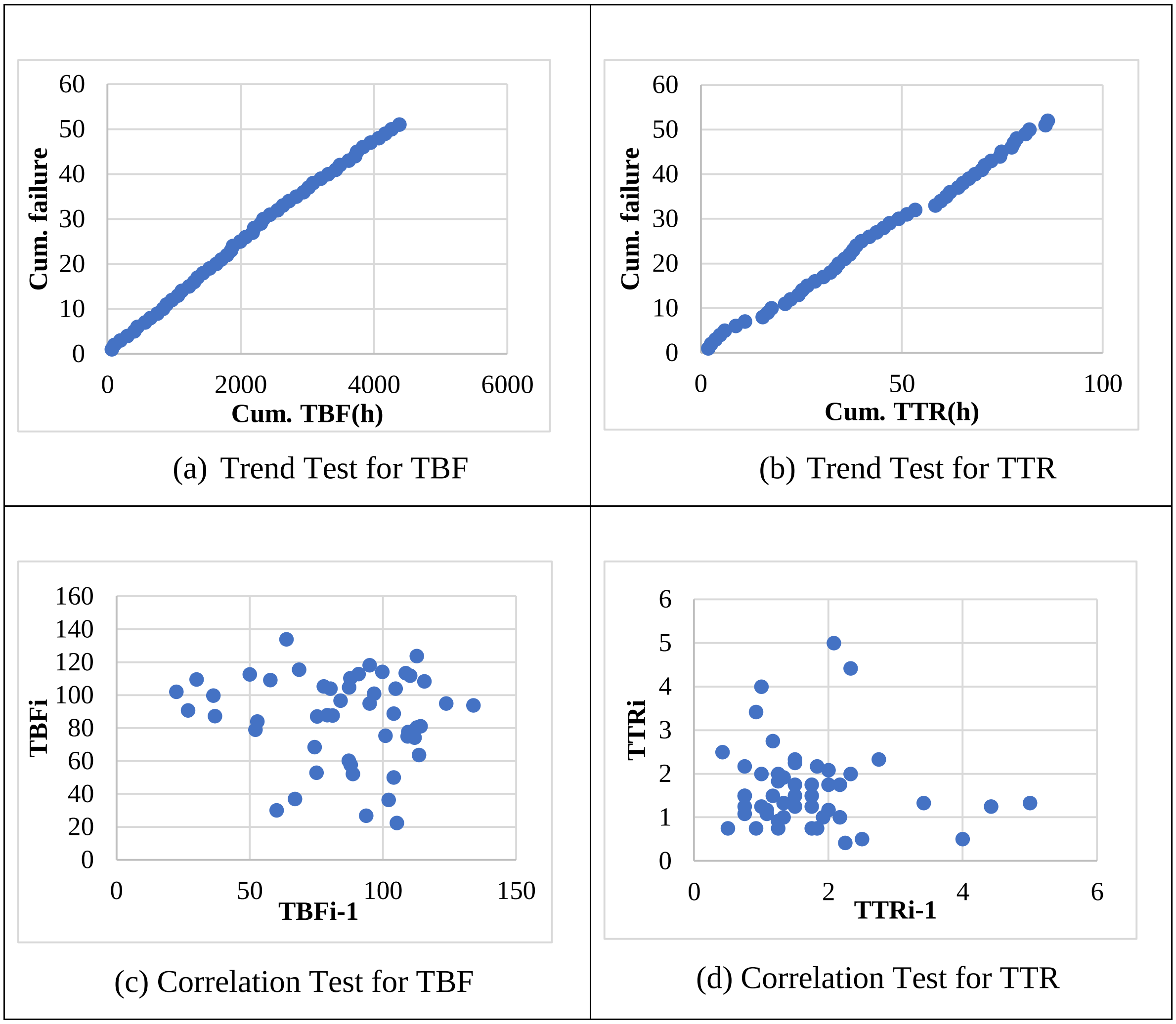


(c) Correlation Test for TBF



(d) Correlation Test for TTR

Figure 4.2: Subsystem C1 (a) trend test for TBF (b) trend test for TTR (c) correlation test for TBF (d) correlation test for TTR



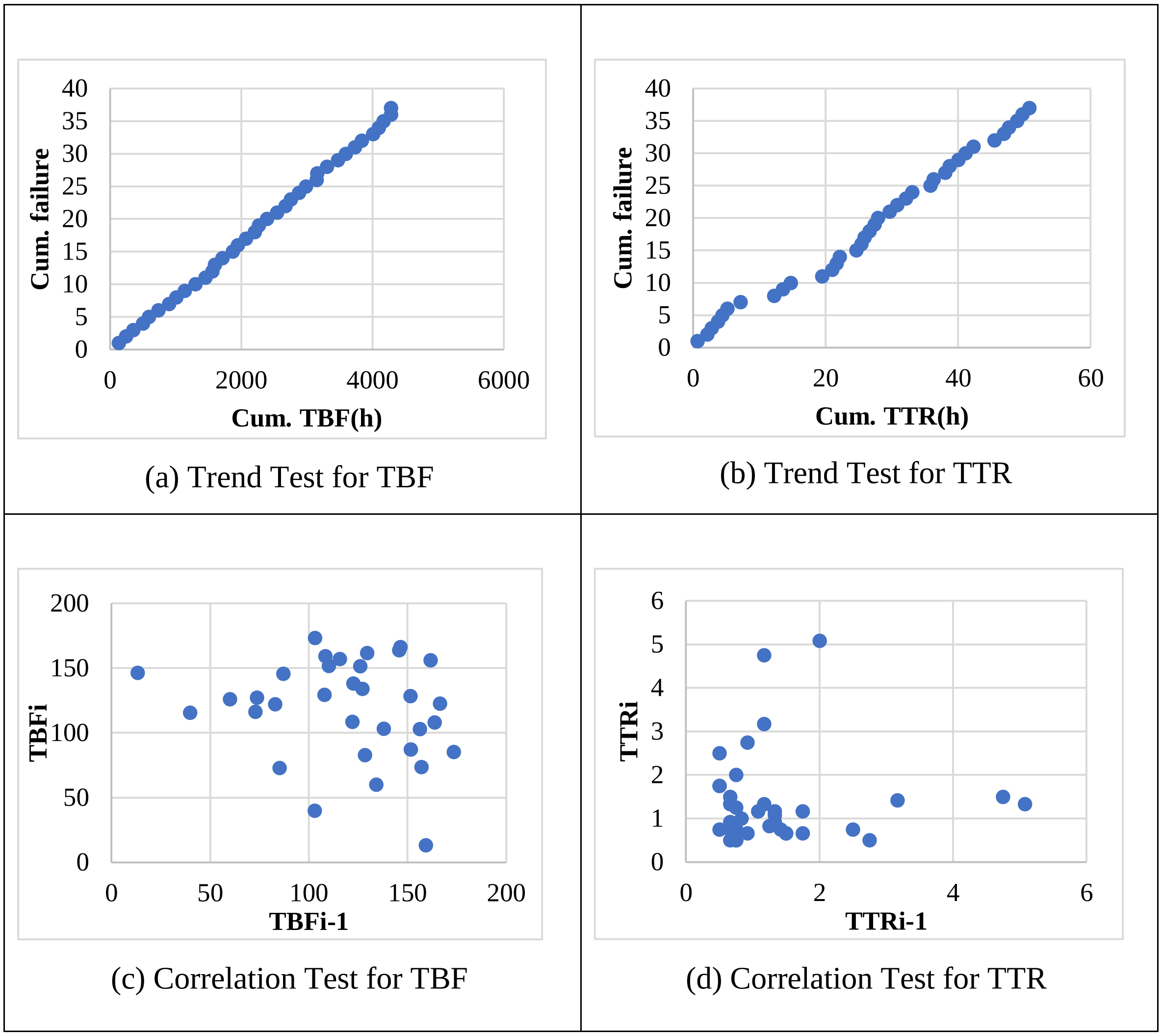
(a) Trend Test for TBF

(b) Trend Test for TTR

(c) Correlation Test for TBF

(d) Correlation Test for TTR

Figure 4.3: Subsystem C2 (a) trend test for TBF (b) trend test for TTR (c) correlation test for TBF (d) correlation test for TTR



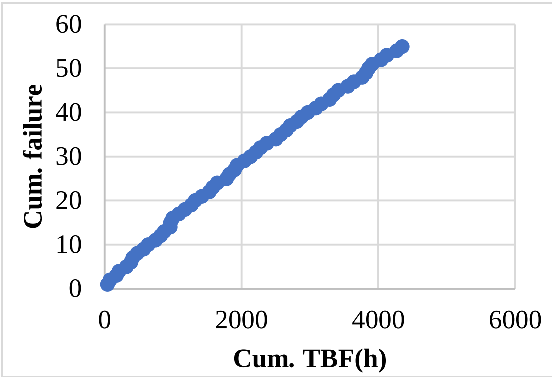
(a) Trend Test for TBF

(b) Trend Test for TTR

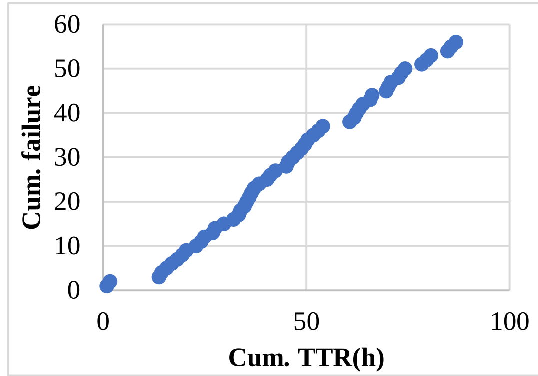
(c) Correlation Test for TBF

(d) Correlation Test for TTR

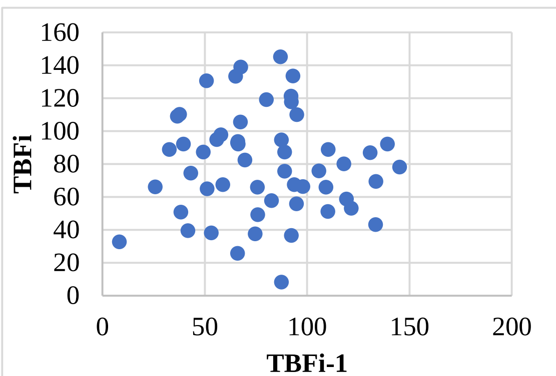
Figure 4.4: Subsystem C3 (a) trend test for TBF (b) trend test for TTR (c) correlation test for TBF (d) correlation test for TTR



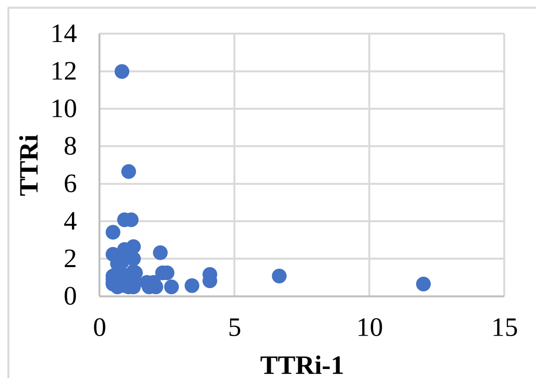
(a) Trend Test for TBF



(b) Trend Test for TTR

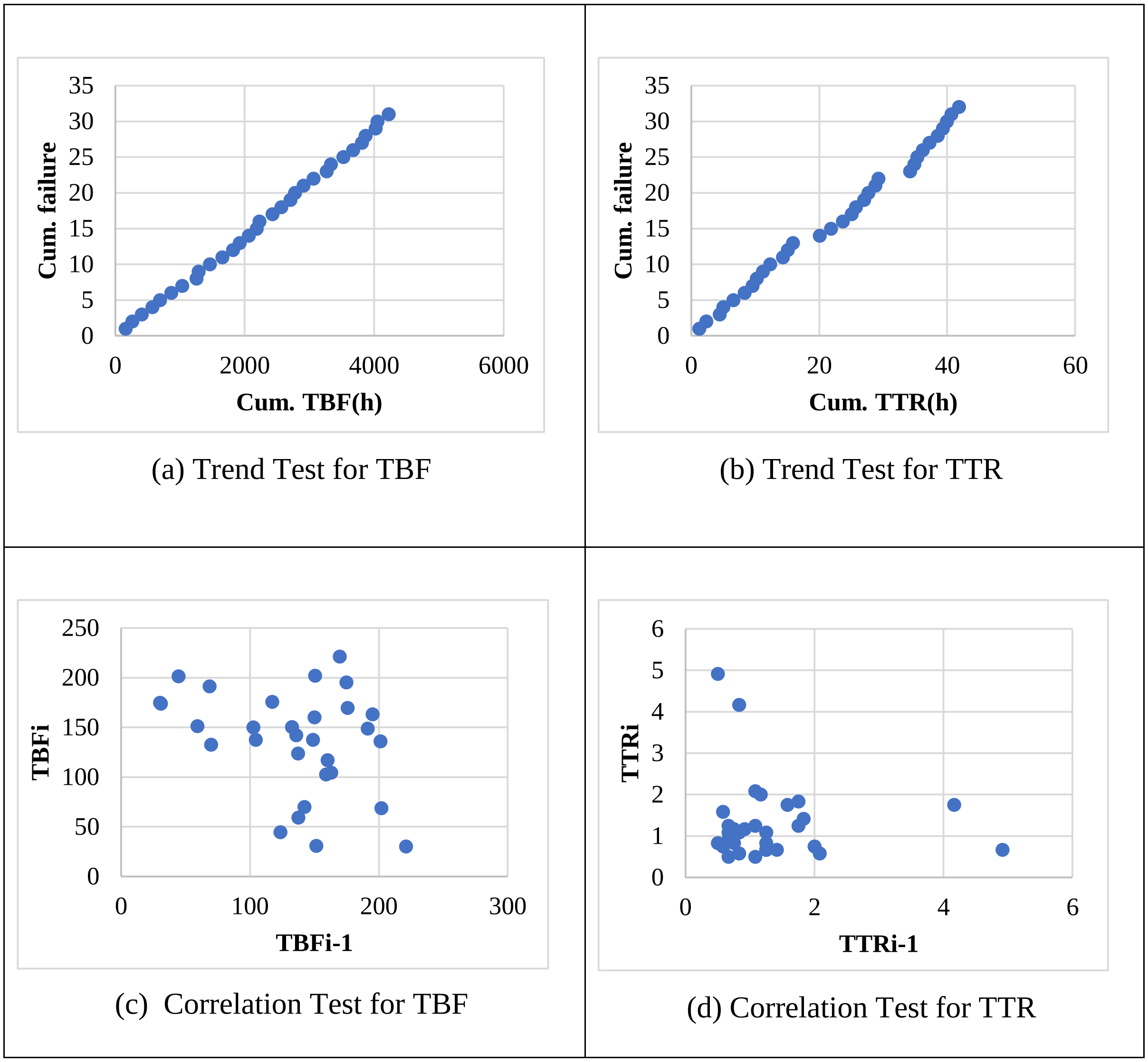


(c) Correlation Test for TBF



(d) Correlation Test for TTR

Figure 4.5: Subsystem C4 (a) trend test for TBF (b) trend test for TTR (c) correlation test for TBF (d) correlation test for TTR



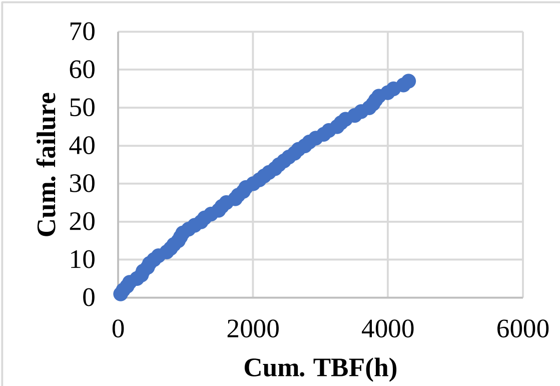
(a) Trend Test for TBF

(b) Trend Test for TTR

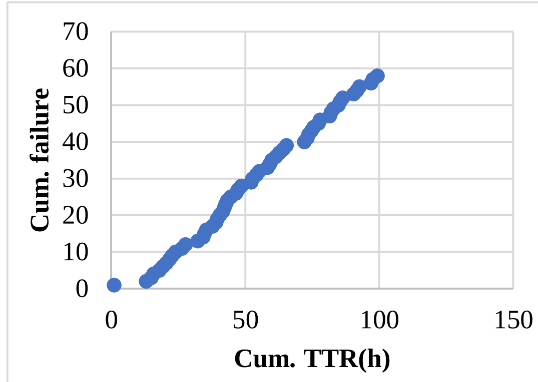
(c) Correlation Test for TBF

(d) Correlation Test for TTR

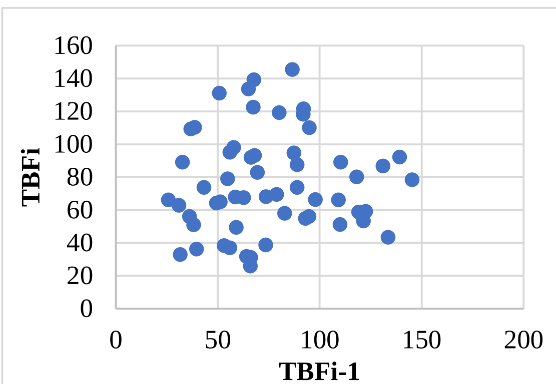
Figure 4.6: Subsystem C5 (a) trend test for TBF (b) trend test for TTR (c) correlation test for TBF (d) correlation test for TTR



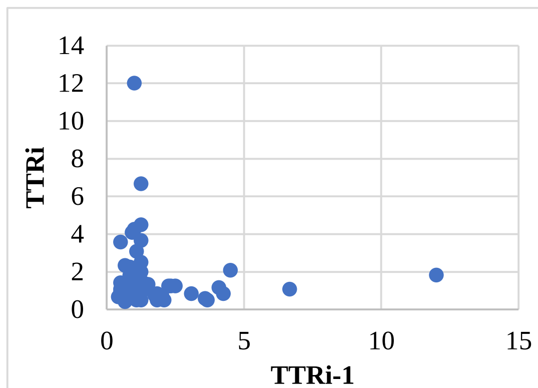
(a) Trend Test for TBF



(b) Trend Test for TTR

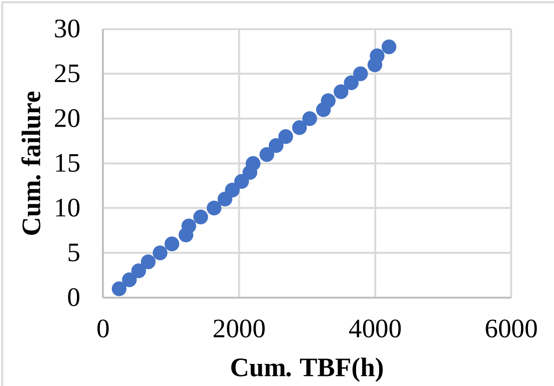


(c) Correlation Test for TBF

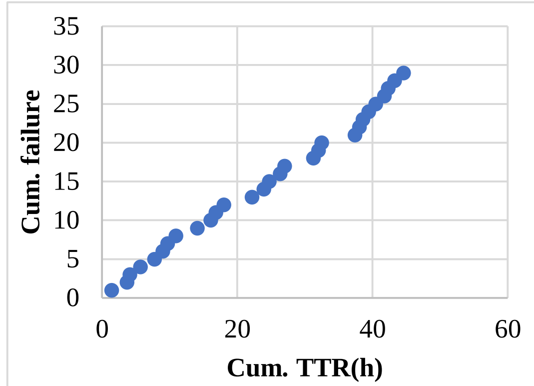


(d) Correlation Test for TTR

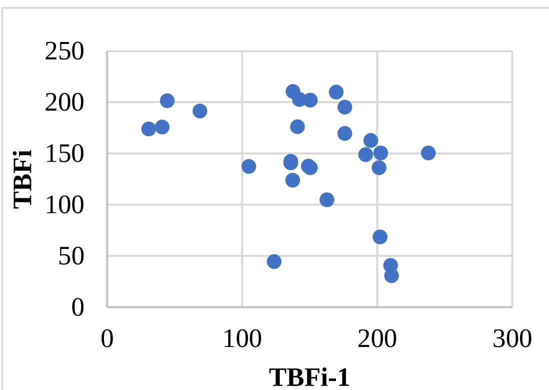
Figure 4.7: Subsystem C6 (a) trend test for TBF (b) trend test for TTR (c) correlation test for TBF (d) correlation test for TTR



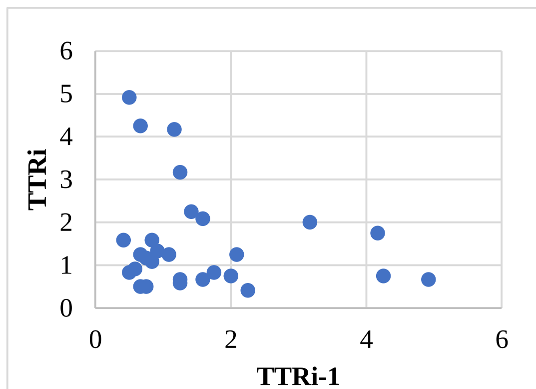
(a) Trend Test for TBF



(b) Trend Test for TTR



(c) Correlation Test for TBF



(d) Correlation Test for TTR

Figure 4.8: Subsystem C7 (a) trend test for TBF (b) trend test for TTR (c) correlation test for TBF (d) correlation test for TTR

4.4 U-Statistic Test

The next step after the collection, sorting and classification of the data is the validation of the IID nature of the TBF and TTR data for each subsystem. This was done by U-statistic test (a null hypothesis test). The computed values of the test statistic for the different subsystem failures and repairs data are given in Table 4.3. It was found that the null hypothesis was not rejected at a 5% level of significance for all the subsystems. That is the statistical test matches the results obtained in trend test and serial correlation test. In the serial correlation test, the points are randomly scattered in the case of the conveyor belt subsystems, which exhibited no correlation. The results from the trend test and the test for serial correlation show that the data sets of all the subsystems are free from the presence of trends and serial correlation. Thus, the assumption that the data sets are IID is fulfilled for all the subsystems.

Table 4.3: U-statistic Test results for TBF and TTR data

Subsystem	Dataset	Degree of Freedom	Calculated statistic U	Rejection of Null Hypothesis at 5% level of significance	Status
C1	TBF	102	99.64	79.7	No Reject
	TTR	104	115.23	81.5	No Reject
C2	TBF	100	103.75	78.0	No Reject
	TTR	102	98.036	79.7	No Reject
C3	TBF	70	64.554	51.8	No Reject
	TTR	72	70.444	53.5	No Reject
C4	TBF	108	119.522	85.0	No Reject
	TTR	110	93.694	86.8	No Reject
C5	TBF	60	53.912	43.2	No Reject
	TTR	62	56.556	44.8	No Reject
C6	TBF	112	128.56	88.5	No Reject
	TTR	114	91.788	90.4	No Reject
C7	TBF	54	47.144	38.2	No Reject
	TTR	56	51.044	39.8	No Reject

4.5 Kolmogorov-Smirnov (K-S) test

The next step of the proposed work is to analyze the best-fit distribution functions for TBF and TTR data. The best fit analyses were conducted using Kolmogorov-Smirnov (K-S) test. The principle behind goodness-of-fit tests is to see how far the chosen distribution is from the actual data set, or in other words how well the chosen distribution represent the observed distribution. Six common probability distribution functions (Weibull 3-parameter, Weibull 2-parameter, Lognormal 3-parameter, Lognormal 2-parameter, Exponential 2-parameter, and Normal distribution) were examined for modeling the failure data and repair data for each subsystem. These six distributions are well known to be appropriate for modeling failures of mechanical systems, as well as having different characteristics to cover a wide area of types of data. To determine the best-fitted distribution for the datasets the modified K-S goodness-of-fit test have been used. The parameters for the distributions were estimated using the MLE method. The modified K-S test and the parameter estimation of probability distribution functions using MLE were conducted using the Easy Fit reliability software package. The results of the modified K-S test for the six distributions, the best-fitted distribution, and estimated parameters of the best-fitted distribution function for TBF and TTR data are listed in Table 4.4 and Table 4.5 respectively.

Table 4.4: Best-fit distribution for TBF data

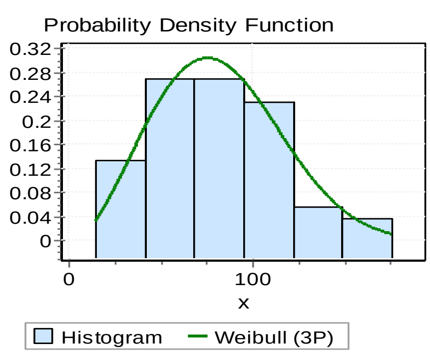
Best-fit distribution for TBF data								
Sub-system	K-S test (goodness of fit)						Best-fit	Parameters
	Exponential 2 parameter	Log-normal	Log-normal 3 parameter	Normal	Weibull 2 parameter	Weibull 3 parameter		
C1	0.2614	0.1054	0.056	0.0699	0.06249	0.05096	Weibull 3 parameter	α=2.4619 β=88.113 γ=4.4859
C2	0.304	0.169	0.112	0.108	0.131	0.068	Weibull 3 parameter	α=40.2 β=866.0 γ=-769.0
C3	0.35	0.223	0.122	0.111	0.203	0.075	Weibull 3 parameter	α=3.04E+7 β=8.65E+8 γ=-8.65E+8
C4	0.276	0.131	0.067	0.069	0.087	0.07	Log-normal 3 parameter	σ=0.061 μ=6.22 γ=-427.0
C5	0.301	0.237	0.151	0.148	0.188	0.094	Weibull 3 parameter	α=23.0 β=954.0 γ=-795.0
C6	0.202	0.069	0.064	0.108	0.078	0.059	Weibull 3 parameter	α=1.82 β=99.8 γ=-22.3
C7	0.371	0.284	0.181	0.181	0.242	0.117	Weibull 3 parameter	α=51.5 β=2.16E+3 γ=-1.99E+3

Table 4.5: Best-fit distribution for TTR data

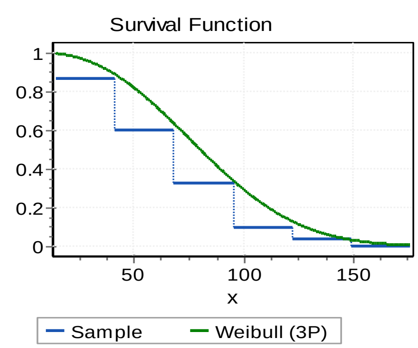
Best-fit distribution for TTR data								
Sub-system	K-S test (goodness of fit)						Best-fit	Parameters
	Exponential 2-parameter	Log-normal	Log-normal 3-parameter	Normal	Weibull 2-parameter	Weibull 3-parameter		
C1	0.2058	0.134	0.074	0.2734	0.1730	0.1553	Log-normal 3 parameter	σ=1.23 μ=0.019 γ=0.378
C2	0.182	0.065	0.065	0.144	0.092	0.087	Log-normal	σ=0.522 μ=0.369
C3	0.129	0.13	0.098	0.236	0.125	0.138	Log-normal 3 parameter	σ=1.08 μ=-0.592 γ=0.431
C4	0.276	0.187	0.113	0.317	0.223	0.152	Log-normal 3 parameter	σ=1.2 μ=-0.608 γ=0.448
C5	0.318	0.127	0.122	0.242	0.144	0.122	Log-normal 3 parameter	σ=0.949 μ=-0.555 γ=0.422
C6	0.152	0.138	0.084	0.254	0.177	0.114	Log-normal 3 parameter	σ=0.999 μ=-0.206 γ=0.352
C7	0.077	0.101	0.084	0.209	0.101	0.107	Exponential 2 parameter	λ=0.892 γ=0.416

The plot of the best-fitted probability density function and the corresponding survival function for the TBF data of subsystem C1 are shown in Figure 4.9(a) and Figure 4.9(b) respectively. It is clear from Table 4.10 that the best-fit distribution for the failure data of subsystem C1 is Weibull 3-parameter distribution function. It was determined based on the K-S test results. The lowest value of K-S test is the best-fitted model. The shape parameter (α), the scale parameter (β) and the location parameter (γ) of Weibull 3-distribution functions were found to be 2.4619, 88.113, and 4.4859 respectively.

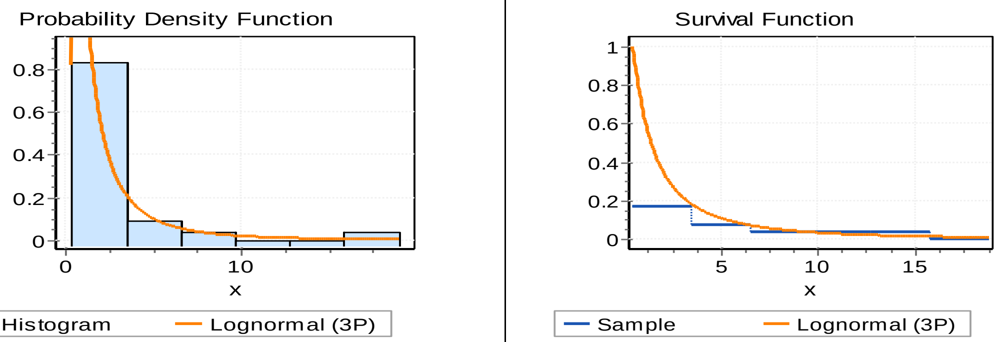
Similarly, Figure 4.9(c) and Figure 4.9(d) represent the plots of best-fit probability density function (PDF) and the corresponding survival function for TTR data of subsystem C1 respectively. The best fit distribution for the repair data of subsystem C1 is Lognormal 3-parameter distribution function. The value of the standard deviation (σ), the mean of the natural logarithm (μ), and the location parameter (γ) of the distribution function were found to be 1.23, 0.019, and 0.378 respectively.



(a) Probability density function for TBF



(b) Survival function for TBF

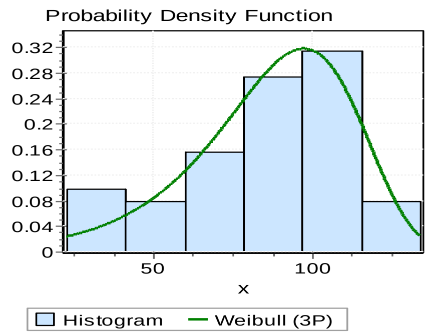


(C) Probability density function for TTR (d) Survival function for TTR

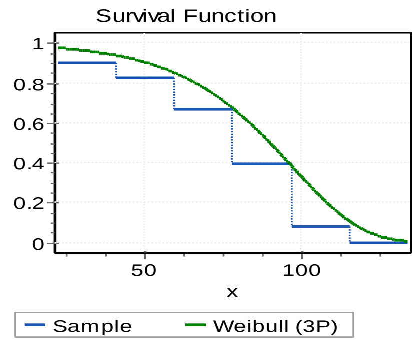
Figure 4.9: Subsystem C1 (a) Probability density function for TBF (b) Survival function for TBF (c) Probability density function for TTR (d) Survival function for TTR

Similarly, the plot of the best fit probability density function and survival function for TBF of subsystem C2 are shown in Figure 4.10(a) and Figure 4.10(b) respectively. In this case also, the best-fit distribution function is Weibull 3-parameter. The shape parameter (α), the scale parameter (β) and the location parameter (γ) of Weibull 3-distribution functions were found to be 40.2, 866, 769 respectively.

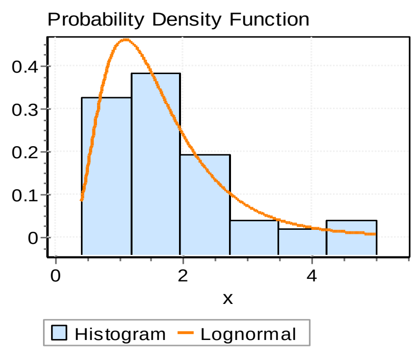
Figure 4.10(c) and Figure 4.10(d) represent the plots of best-fit probability density function (PDF) and the corresponding survival function for TTR data of subsystem C2 respectively. It is clear from Table 4.11 that the best-fit distribution for the repair data of subsystem C2 is Lognormal 2-parameter distribution function. The value of the standard deviation (σ), and the mean (μ) of the natural logarithm of the distribution function were found to be 0.522, and 0.369 respectively.



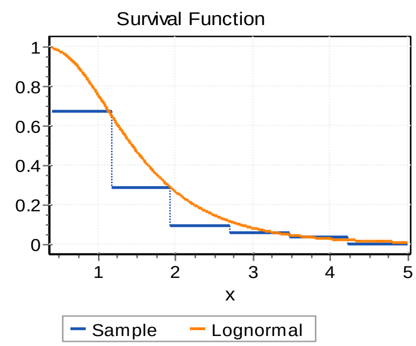
(a) Probability density function for TBF



(b) Survival function for TTR



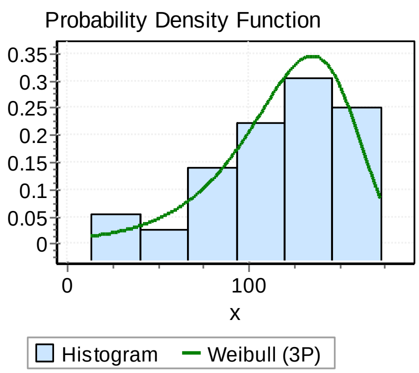
(C) Probability density function for TTR



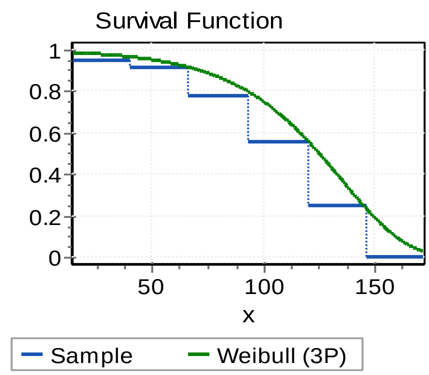
(d) Survival function for TTR

Figure 4.10: Subsystem C2 (a) Probability density function for TBF (b) Survival function for TBF (c) Probability density function for TTR (d) Survival function for TTR

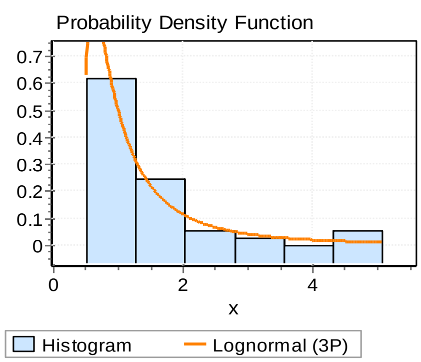
The plot of the best-fitted probability density function and the corresponding survival function for the TBF data of subsystem C3 are shown in Figure 4.11(a) and Figure 4.11(b) respectively. The best fit distribution for the failure data of subsystem C3 is Weibull 3-parameter distribution function. The shape parameter (α), the scale parameter (β) and the location parameter (γ) of Weibull 3-distribution functions were found to be 3.04E+7, 8.65E+8, -8.65E+8 respectively. Similarly, Figure 4.11(c) and Figure 4.11(d) represent the plots of best-fit probability density function (PDF) and the corresponding survival function for TTR data of subsystem C3 respectively. The best fit distribution for the repair data of subsystem C3 is Lognormal 3-parameter distribution function. The value of the standard deviation (σ), the mean of the natural logarithm (μ), and the location parameter (γ) of the distribution function were found to be 1.08, 0.592, and 0.431 respectively.



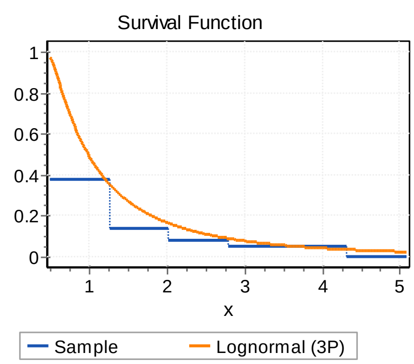
(a) Probability density function for TBF



(b) Survival function for TBF



(C) Probability density function for TTR

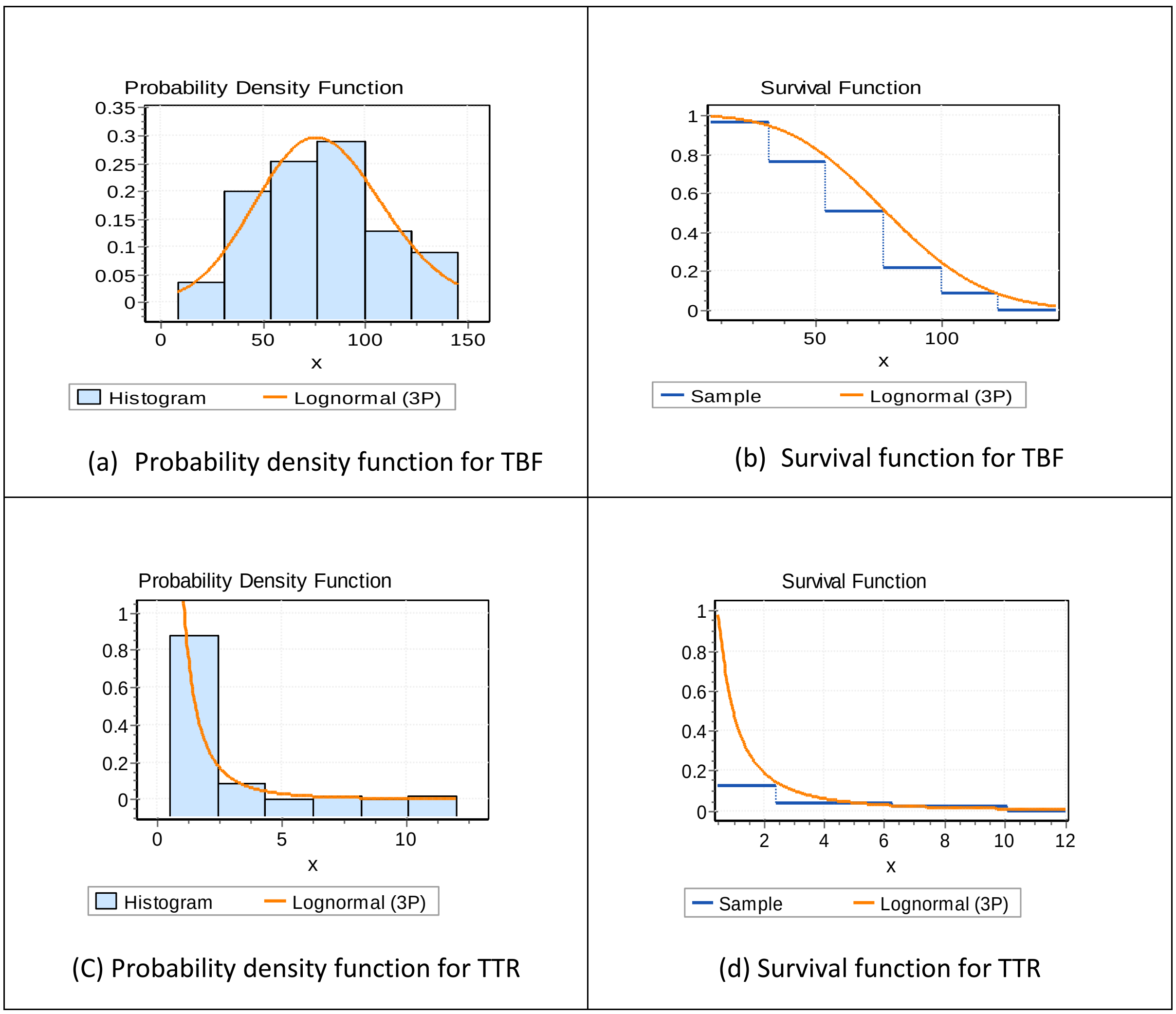


(d) Survival function for TTR

Figure 4.11: Subsystem C3 (a) Probability density function for TBF (b) Survival function for TBF (c) Probability density function for TTR (d) Survival function for TTR

The plot of the best-fitted probability density function and the corresponding survival function for the TBF data of subsystem C4 are shown in Figure 4.12(a) and Figure 4.12(b) respectively. It is clear from Table 4.10 that the best-fit distribution for the failure data of subsystem C1 is Lognormal 3-parameter distribution function. The respective values of the standard deviation (σ), the mean of the natural logarithm (μ), and the location parameter (γ) of the distribution function were observed as 0.061, 6.22, and 427.

Similarly, Figure 4.12(c) and Figure 4.12(d) represent the plots of best-fit probability density function (PDF) and the corresponding survival function for TTR data of subsystem C4 respectively. Lognormal 3-parameter distribution function was observed as the best fit distribution for the repair data of subsystem C4. The respective values of the standard deviation (σ), the mean of the natural logarithm (μ), and the location parameter (γ) of the distribution function were found to be 1.2, 0.608, and 0.448.



(a) Probability density function for TBF

(b) Survival function for TBF

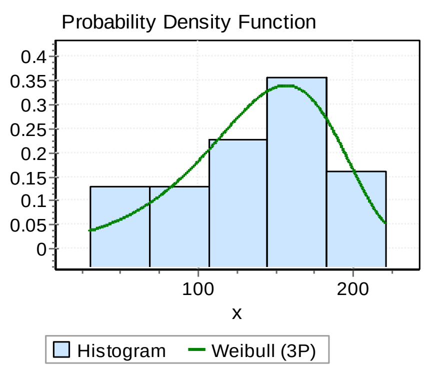
(C) Probability density function for TTR

(d) Survival function for TTR

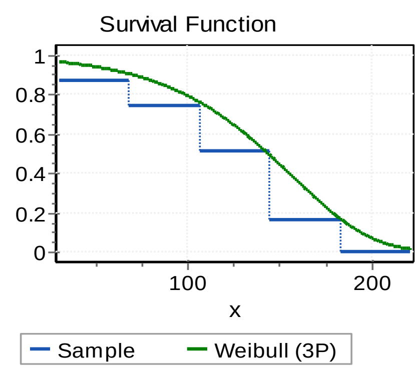
Figure 4.12: Subsystem C5 (a) Probability density function for TBF (b) Survival function for TBF (c) Probability density function for TTR (d) Survival function for TTR

The plot of the best fitted probability density function and the corresponding survival function for the TBF data of subsystem C5 are shown in Figure 4.13(a) and Figure 4.13(b) respectively. It is clear from Table 4.10 that the best-fit distribution for the failure data of subsystem C5 is Weibull 3-parameter distribution function. The respective values of the shape parameter (α), the scale parameter (β), and the location parameter (γ) of Weibull 3-distribution function were observed as 23, 954, and 795.

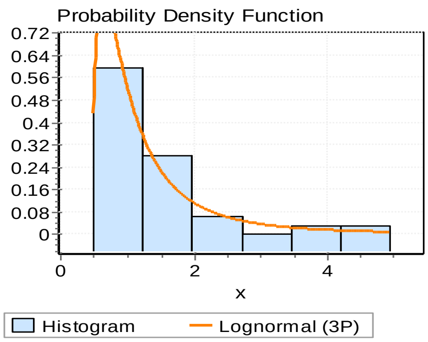
Similarly, Figure 4.13(c) and Figure 4.13(d) represent the plots of best-fit probability density function (PDF) and the corresponding survival function for TTR data of subsystem C5 respectively. Lognormal 3-parameter distribution function was observed as the best fit distribution for the repair data of subsystem C5. The respective values of the standard deviation (σ), the mean of the natural logarithm (μ), and the location parameter (γ) of the distribution function were found to be 0.949, 0.555, and 0.422.



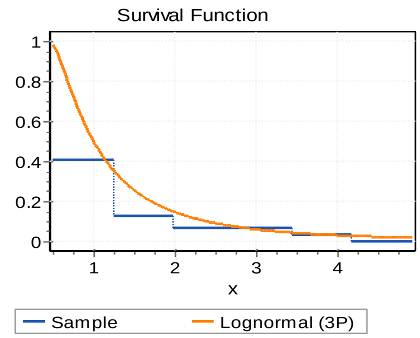
(a) Probability density function for TBF



(b) Survival function for TBF



(C) Probability density function for TTR

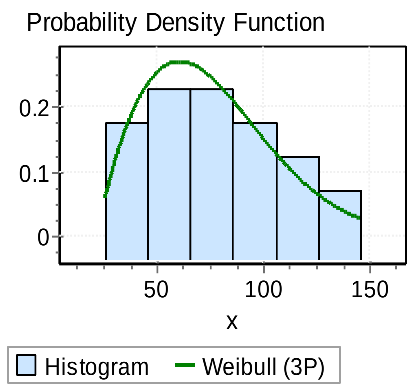


(d) Survival function for TTR

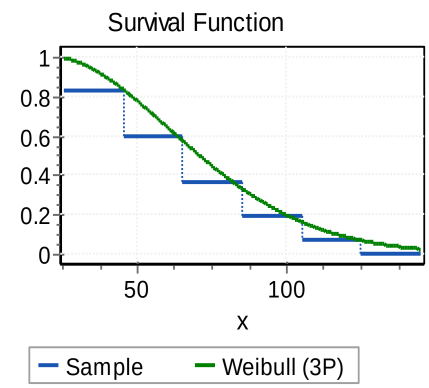
Figure 4.13: Subsystem C5 (a) Probability density function for TBF (b) Survival function for TBF (c) Probability density function for TTR (d) Survival function for TTR

The plot of the best-fitted probability density function and the corresponding survival function for the TBF data of subsystem C6 are shown in Figure 4.14(a) and Figure 4.14(b) respectively. It is clear from Table 4.10 that the best-fit distribution for the failure data of subsystem C6 is Weibull 3-parameter distribution function. The respective values of the shape parameter (α), the scale parameter (β), and the location parameter (γ) of Weibull 3-distribution function were observed as 1.82, 99.8, and 22.3.

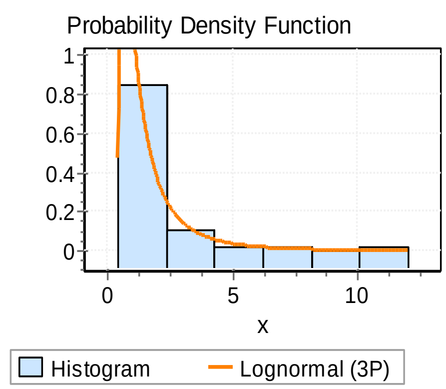
Similarly, Figure 4.14(c) and Figure 4.14(d) represent the plots of best-fit probability density function (PDF) and the corresponding survival function for TTR data of subsystem C6 respectively. Lognormal 3-parameter distribution function was observed as the best fit distribution for the repair data of subsystem C6. The respective values of the standard deviation (σ), the mean of the natural logarithm (μ), and the location parameter (γ) of the distribution function were found to be 0.999, 0.206, and 0.352.



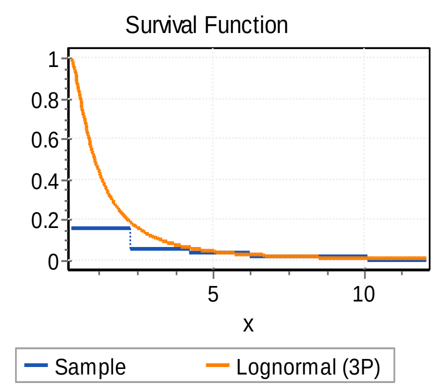
(a) Probability density function for TBF



(b) Survival function for TBF



(C) Probability density function for TTR

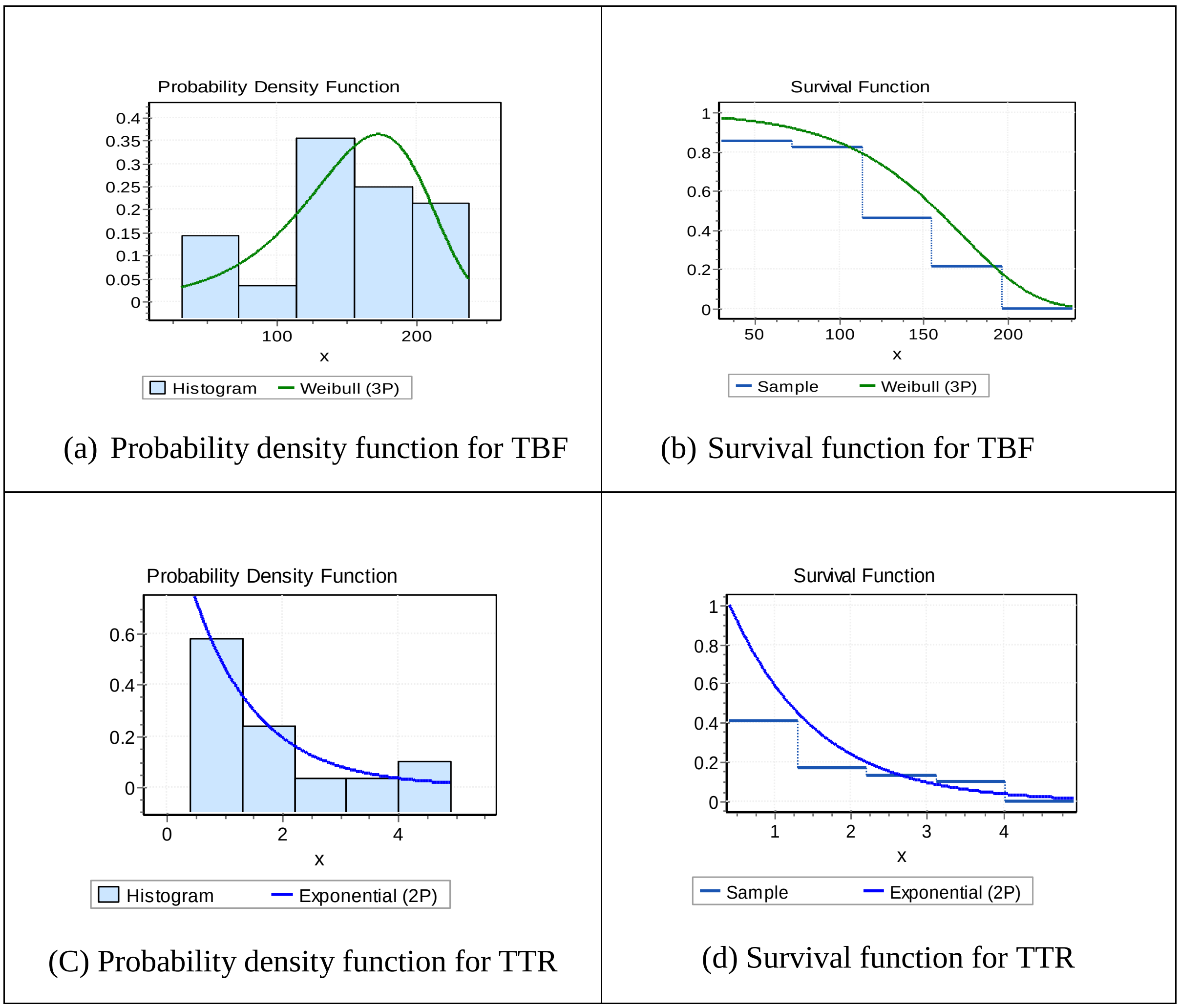


(d) Survival function for TTR

Figure 4.14: Subsystem C6 (a) Probability density function for TBF (b) Survival function for TBF (c) Probability density function for TTR (d) Survival function for TTR

The plot of the best-fitted probability density function and the corresponding survival function for the TBF data of subsystem C7 are shown in Figure 4.15(a) and Figure 4.15(b) respectively. It is clear from Table 4.10 that the best-fit distribution for the failure data of subsystem C7 is Weibull 3-parameter distribution function. The respective values of the shape parameter (α), the scale parameter (β) and the location parameter (γ) of Weibull 3-distribution function were observed as 51.5, 2.16E+3, and 1.99E+3.

Similarly, Figure 4.15(c) and Figure 4.15(d) represent the plots of best-fit probability density function (PDF) and the corresponding survival function for TTR data of subsystem C6 respectively. Exponential 2-parameter distribution function was observed as the best fit distribution for the repair data of subsystem C7. The respective values of the constant failure rate (λ) and the location parameter (γ) of the distribution function were found to be 0.892, and 0.416.



(a) Probability density function for TBF

(b) Survival function for TBF

(C) Probability density function for TTR

(d) Survival function for TTR

Figure 4.15: Subsystem C7 (a) Probability density function for TBF (b) Survival function for TBF (c) Probability density function for TTR (d) Survival function for TTR

4.6 Determination of Reliability Availability and Maintainability

Availability of each subsystem were determined from the following formula:

$$A = \frac{MTBF}{MTBF + MTTR}$$

Where, MTBF and MTTR are the mean time between failure and mean time to repair.

The values of MTBF for each subsystem were determined by dividing the cumulative time between failure (CTBF) with the total number (frequency) of failure. Similarly, the MTTRs for each subsystem were determined by dividing the cumulative time to repair with the total number (frequency) of failure. The respective values of MTBF and MTTR for each subsystem along with the frequency of failure are produced in Table 4.6. It is clear from the results that all the subsystems are available for more than 97 % of the time.

Table 4.6: Availability of each subsystem

Subsystem	Frequency	MTBF	MTTR	Availability
C1	53	82.68	2.548	0.97
C2	52	85.82	1.65	0.98
C3	37	119.0325	1.37	0.99
C4	56	79.09	1.549	0.98
C5	32	136.324	1.306	0.99
C6	58	75.581	1.712	0.98
C7	29	150.074	1.537	0.99

Reliability of each subsystem were determined from the corresponding best-fit probability distribution functions. The best fit functions used for calculating the reliability of seven subsystems (C1, C2, C3, C4, C5, C6, and C7) are respectively Weibull 3-Parameter, Weibull 3-Parameter, Weibull 3-Parameter, Lognormal 3-Parameter, Weibull 3-Parameter, Weibull 3-Parameter, and Weibull 3-Parameter. The reliability of each subsystem were determined for 5 operational times (10 hrs., 20 hrs., 40 hrs., 60 hrs., and 80 hrs.). The results are produced in Table 4.7. The results shown in Table 4.7 clearly indicates that the subsystem C6 has the worst level of reliability with a time of operation. The reliability of this subsystem for 80-hr operation is only 35.1 %.

Table 4.7: Reliability of the subsystems of main conveyor system

Subsystem	**Time (hour)**				
	10	**20**	**40**	**60**	**80**
C1	0.999	0.986	0.899	0.725	0.505
C2	0.986	0.977	0.937	0.841	0.637
C3	0.940	0.930	0.900	0.800	0.500
C4	0.960	0.940	0.920	0.860	0.820
C5	0.980	0.974	0.954	0.923	0.872
C6	0.879	0.810	0.654	0.494	0.351
C7	0.983	0.978	0.964	0.942	0.905

4.7 Reliability based time intervals for preventive maintenance

To improve the reliability of the system preventive maintenance is needed for each subsystem. Since the reliability of different subsystem was different, the maintenance time interval for different subsystem will also be different. The maintenance time interval for each subsystem of the main conveyor system were determined for 80 % reliability of the system. The time interval for each subsystem were calculated from the corresponding reliability functions. The results are produced in Table 4.8. The subsystems C1, C2, C3, C4, C5, C6, and C7 requires maintenance in the interval of 52.39 hrs., 65.28 hrs., 60.00 hrs., 84.66 hrs., 98.77 hrs., 20.89 hrs., and 112.85 hrs. respectively. It can be easily inferred from the results that the reliability based time intervals for preventive maintenance is lowest for subsystem C6 and highest for subsystem C7. That is, subsystem C6 requires maintenance in every 20.89 hrs. and subsystem C7 requires maintenance in every 112.85 hrs. for maintaining the 80 % reliability of the main conveyor system.

Table 4.8: Reliability based time intervals for preventive maintenance

Level of reliability (%)	C1	C2	C3	C4	C5	C6	C7
80	52.39 hrs.	65.28 hrs.	60.00 hrs.	84.66 hrs.	98.77 hrs.	20.89 hrs.	112.85 hrs.

Chapter 5

Conclusions

Reliability, availability and maintainability analyses should always be an integral part of mining engineering and management for the effective utilization of mining equipment in the mine. The primary objective of the present study is to analyze reliability, availability and maintainability of the main conveyor system in the underground coal mine. The study was conducted with the failure and repair data of Churcha (RO) mine. The mine is working under the management of South Eastern Coalfield Limited (SECL). The research study illustrates how the reliability and maintainability of the conveyor system affect the overall productivity of the mine. The main conveyor system of the mine has seven subsystems.

The availability results indicated that all the subsystems (C1 to C7) are available for more than 97 % of the time.

Reliability of each subsystem was determined from the corresponding best-fit probability distribution functions. The respective best-fit probability density functions for seven subsystems (C1, C2, C3, C4, C5, C6, and C7) were observed as Weibull 3-Parameter, Weibull 3-Parameter, Weibull 3-Parameter, Lognormal 3-Parameter, Weibull 3-Parameter, Weibull 3-Parameter, and Weibull 3-Parameter. The results revealed that the subsystem C6 has the worst level of reliability and C7 has the maximum level of reliability.

To improve the reliability of the system preventive maintenance is needed for each subsystem. The maintenance time interval for each subsystem of the main conveyor system was determined for 80 % reliability of the system. The subsystems C1, C2, C3, C4, C5, C6, and C7 requires maintenance in the interval of 52.39 hrs., 65.28 hrs., 60.00 hrs., 84.66 hrs., 98.77 hrs., 20.89 hrs., and 112.85 hrs. respectively for 80 % reliability of the system. It can be easily inferred from the results that the reliability based time intervals for preventive maintenance are lowest for subsystem C6 and highest for subsystem C7. That is, subsystem C6 requires maintenance in every 20.89 hrs. and subsystem C7 requires maintenance in every 112.85 hrs. for maintaining the 80 % reliability of the main conveyor system.

One should take the subsystem with a low level of reliability seriously and consider for making changes to the maintenance policy of such subsystem for improvement.

The bulk of maintenance is done for correcting in the unscheduled and unplanned way. It may, therefore, be a high cost related to the high frequency of failure. Maintenance costs may by lowered by increasing the preventive work for the conveyors. The production in the mine can also be improved with the scheduled maintenance of the subsystems.

This major limitation of the above studies the limited availability of the failure and repair data. The study uses only six months' data (July-December 2015). The other limitation is that it was assumed that all influence factors are included in the model.

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