IMPROVEMENT OF SHOVEL AND DUMPER AVAILABILITY IN INDIAN SURFACE MINES USING RELIABILITY ANALYSIS

Thesis

Submitted in partial fulfilment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

by

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D E C L A R A T I O N

by the Ph. D Scholar

I hereby declare that the Research Thesis entitled **“Improvement of Shovel and Dumper Availability in Indian Surface Mines using Reliability Analysis”** which is being submitted to the **National Institute of Technology Karnataka, Surathkal** in partial fulfillment of the requirements for the award of the Degree of **Doctor of Philosophy** in **Mining Engineering** is a bonafide report of the research work carried out by me. The material contained in this Research Thesis has not been submitted to any University or Institution for the award of any degree.

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C E R T I F I C A T E

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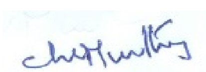

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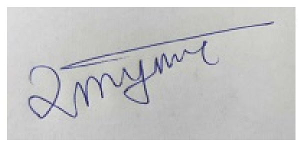

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DEDICATED
TO
MY FAMILY,
MY TEACHERS AND
MY FRIENDS

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ABSTRACT

Reliability, Availability and Maintainability (RAM) analysis of mining equipment is essential to reduce breakdown hours, operational cost and capital cost and enhance mineral production. The expenditure on mining equipment and expertise increases with the size and complexity of the equipment. A survey of the literature showed that no studies are available on reliability approaches based on subsystems using Markov and RBD model and studies that included mining factors, although a lot of studies exist on shovel and dumper. Consequently, the literature throws little light on the comparison of different reliability approaches between different mines, which is necessary to understand different mine factors. Therefore, the present study attempted to develop mathematical models based on reliability for shovel-dumper system for different surface mines (surface coal mine, surface iron ore mine and surface limestone mine) and determine the life of subsystem. The study aims to overcome the major challenges in the mining engineering equipment of breakdown, complexity, size, competition, cost and safety of equipment as well as increased use of mechanization, automation and amalgamation.

The research was carried out using quantitative approach as the present study determines the reliability in mining sector. The failure data were collected over a period of one years from daily downtime reports and maintenance records from SCCL, Telengana (for coal mine), M/s. Subbarayanahalli Iron Ore mines and M/s. Mysore Minerals, Sandure (for iron ore) and Thummalapenta Limestone Mine, Telangana (for limestone). To ensure that the data are independent and identically distributed (IID), the trend and serial correlation test were conducted. The analysis of the data was performed using Isograph Reliability Workbench software and characterised by Reliability Block Modelling (RBD) and Morkov modelling. To model the failure and repair processes of subsystems, RAM analysis using time between the failure (TBF) and time to repair (TTR) were carried out.

The match factor for coal mine was 1:4, while it was 1:3 for iron ore and limestone mine, which led to the selection of two shovels and eight dumpers for coal mine and two shovels and six dumpers each for iron ore and limestone mine. A total of ten subsystems were formed for the shovel and dumper system. The highest failure percentage for coal mine was 42.1%

and 48.3% for iron ore mine and limestone mine. Further, in trend and serial correlation analysis, no trend was observed between TBF and TTR was observed and the IID assumption was proved.

The Kolmogorov-Smirnov test (K-S test) yielded the probability distribution functions for different subsystems of shovel-dumper system for coal mine as shovels as 0.373 (KS1) and 0.285 (KS2) and dumpers have 0.356 (BD3), 0.269 (BD4), 0.347 (BD5), 0.334 (BD6), 0.332 (KD7), 0.275 (KD8) 0.268 (KD9) and 0.291 (KD10); for iron ore mine as shovels have 0.312 (KS11) and 0.275 (KS12) reliability and dumpers have 0.359 (BD13), 0.342 (BD14), 0.332 (BD15), 0.409 (KD16), 0.393 (KD17) and 0.394 (KD18) and for limestone mine as shovels, 0.343 (KS19) and 0.348 (KS20) reliability and dumpers, 0.325 (BD21), 0.292 (BD22), 0.329 (BD23), 0.362 (KD24), 0.334 (KD25) and 0.304 (KD26). To improve obtained reliability of each system, the preventive maintenance is needed for each system i.e., shovel and dumper. The time interval for each subsystem of shovel and dumper were determined for the 90%, 80% and 70% of reliability of system.

The different shovel-dumper systems considered in the study showed ‘infant mortality’ failure indicating manufacturing flaws during the early usage of equipment; however, it improved over time. RBD was used to develop mathematical models for series and series-parallel connection of the systems; whereas, Markov modelling was used for simultaneously-active and continuous-time. The mathematical model for series-parallel connection of the shovel and dumpers were developed based on their match factor and best fit distribution to improve the reliability. As well as Markov model also developed for same shovel and dumper for different mines by considering both failure rate and repair rate.

The findings of the study revealed that the method of RAM analysis adopted in the study was highly effective in determining the time-to-failure of the shovel-dumper system that indicated the need for better maintenance plan and design modifications to improve the reliability of the system. The findings showed the necessity of standardizing the maintenance records to include causes and results of failure and delay time condition and providing training to staff on standardization. Creation of a web-based maintenance platform, real-time policies for maintenance, optimization of spare parts, crew members and inspection periods and long-term maintenance plans were also suggested.

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NOMENCLATURE

NHPP: Homogenous and Non-homogenous Poisson Process

ARIMA: Auto Regressive Integrated Moving Average

BEML: Bharat Earth Movers Ltd

KS: Komastu Shovel

KD: Komastu Dumper

BD: BEML Dumper

SS: Shovel Subsystem

DS: Dumper Subsystem

PDF: Probability Density Function

CDF: Cumulative Distribution Function

HEMM Heavy Earth Moving Machineries

IID: Independent and Identical Distribution

KME: Kaplan – Meir Estimation

LHD: Load Haul Dumper

MLE: Maximum Likelihood Estimation

TBF: Time Between Failure

TTR: Time to Repair

MTBF: Mean Time Between Failure

MTTR: Mean Time to Repair

RBD: Reliability Block Diagram

SPN: Stochastic Petri Net

OEE: Overall Equipment Effectiveness

RCM: Reliability Centered Maintenance

RAM: Reliability, Availability and Maintainability

SSE: Stochastic Shovel Effectiveness

TTT: Total Time On Test

CTMC: Continouse Time Markov Chian

DTMC: Discrete Time Markov Chain

R(t): Reliability Function

F(t): Unreliability

M(t): Maitainability Function

A(t): Avaialability Function

h(t): Hazard Rate

T: Time

N: Number Of Failures

f(t): Probability Density Function

$\lambda(t)$: Failure Rate

$\mu(t)$: Repaire Rate

β: Shape Parameter

η: Scale Parameter

γ: Location Parameter

CHAPTER 1

INTRODUCTION

1.1 General

Mining history can be traced back to many thousand years. The methods and equipment used in mining were undergone many changes over the years with the advancement of technology. In surface mines, mining equipment such as shovels and dumpers are essential and should be more efficient. It creates a need for improvement of efficiency by making the equipment's more reliable and with a good maintenance. It may, therefore, many efforts have to be made to increase the reliability or availability of a shovel and dumper in the surface mine in India (Aven 2006).

To increase production and productivity with the technological advancements large capacity shovels and dumpers are now being used in surface mines. The introduction of such sophisticated, capital intensive mining machines such as shovel and dumper in surface mines require achieving the highest levels of reliability and availability during their operation. The machine reliability, availability and maintainability (RAM) have assumed great significance in recent years due to the competitive environment and overall operating cost/production cost (Samanta et al. 2001). To increase the reliability of any shovel and dumper in a surface mine, it is needed to study various types of failures generally occurs under given conditions and determine the necessary improvements or modifications that should be executed. Mathematical models can be developed to improve the availability and reliability of shovel and dumper in surface mines (Dhillon 2008).

The most widely applied system reliability models are reliability block diagram and Markov models based on lifetime distribution models such as Weibull distribution and exponential distribution (Staley and Sutcliffe 1974; Manglik and Ram 2013). The reliability and availability using the reliability block diagram (RBD) and Markov model under Weibull distribution is dependent upon several factors that must be optimized. The optimizing means achieving a maximum or minimum value of the operational parameters. A good profitability requires a highly reliable and availability level of production machinery. Optimal benefits are realized when reliability is designed for all part or components of equipment. However, it is important to improve reliability, availability and maintainability (RAM) throughout the life of the equipment to meet RAM goals and objectives in different types surface mines. The reliability model enables to predict what is affordable and identify undesirable alternatives. There are many factors affect the reliability and availability, and there are many issues that must be addressed. These include effective working hours, failure data or historical failure data (TBF: time between failure and TTR: time to repair) and maintenance of shovel and dumper. Addressing these issues requires general information, reliability modelling, and data analyzing, serial correlation and trend tests. Two other related issues important in the context of product reliability are maintenance and maintainability (Blischke and Murthy 2003; Blischke and Prabhakar 2000). As the size and complexity of equipment continue to increase, the implications of equipment failure become even more critical. According to Blischke and Murthy (2003) and Blischke and Prabhakar (2000), the consequences of failure are many and varied; depending on the continuous working involved, but nearly every failure has an economic impact. A failure in equipment or facility results not only in a loss of productivity, but also in a loss of reliability and availability and may even lead to safety and environmental problems which destroy the company's image. Since failure cannot be prevented entirely, it is important to minimize both its probability of occurrence and the impact of failures when they do occur. This is one of the principal roles of reliability analysis and maintenance (Blischke and Murthy 2003; Blischke and Prabhakar 2000).

1.2 Problem Statement

The study of reliability, maintainability and availability of the any system or subsystem has assumed great significance in recent years due to a competitive environment and overall operating and production costs. Estimation of reliability plays an important role in performance assessment of any system or subsystem. Reliability predictions are important for various purposes, such as production planning, maintenance planning, reliability assessment, fault detection in manufacturing processes, and risk and liability evaluation of several processes and to improve the safety of equipment. The requirements for the availability and reliability study of such systems are desirable. The extent to which results are consistent over time and an accurate representation of the total population under study is referred to as reliability and is more significant in surface mines as large capacity and sophistication are being achieved in surface mine.

The reliability, availability and maintainability (RAM) of subsystems of shovel and dumper in Indian surface mines reduces breakdown hours, improve the reliability and production of mineral to attain optimum profitability. Most of the previous investigations did research on reliability of systems. However, not much work is reported on the reliability of subsystems of a system in the past based on available literature survey.

The objective of this work is to develop a reliability-based mathematical model of shovel and dumper used in three surface mines to improve the reliability and to calculate the life of their subsystem. RBD and Markov model were developed using Weibull distribution the mathematical models were developed along with mathematical models using failure rate. The validation of the mathematical models was done for developed RBD and Markov analysis.

Also, identifies the critical subsystems of shovel and dumper which require further improvement to enhance the reliability. In the study, graphical and analytical techniques have been used to fit probability distributions for characterization of failure data.

1.3 Thesis Layout

The thesis contains 10 chapters. They are,

Chapter 1: This chapter presents the background of the research work. Furthermore, it presents the scope of the work and structure of the thesis.

Chapter 2: Based on a review of literature, this chapter includes a combination of shovels and dumpers are commonly used in Indian surface mines maintenance practices and provides a background to maintenance management approaches and strategies. It also presents the research carried out on surface mining equipment on RAM.

Chapter 3: This chapter presents the detailed discussion of the research objectives, the origin of research and justification of research work.

Chapter 4: In the fourth chapter, the chosen research design and sequence to obtain the objectives of the research work is presented along with the flow chart.

Chapter 5: Fifth chapter demonstrates the field investigations in three different surface mines in India such as coal mine, iron ore mine and limestone mine. The field investigations present the study area, match factor, failure data of shovel and dumper (TBF and TTR), the calculation for mean time between failure (MTBF) and mean time to repair (MTTR) and also reliability parameters such as failure rate and repair rate of each subsystem of shovel and dumper.

Chapter 6: The Serial correlation & trend Tests carried out between TBF, TTR and number of failures of shovel and dumper, and U-Statistic test (Null hypothesis test) were carried to find that the null hypothesis was not rejected at a 5% (0.05) significance level for all the systems. In this chapter the Kolmogorov-Smirnov (K-S) test were carried out for each shovel and dumper using statistical tools Isograph Reliability Workbench based on collected failure data i.e., TBF and TTR. U-Statistic test and K-S test are noticed that, best-fit distributions i.e., Weibull distribution (one, two and three parameters Weibull distribution and Exponential distribution) for the collected failure data.

Chapter 7: In this chapter, the RAM of each shovel and dumper in all three different mines were calculated for their effective working hours per year based on best-fit distribution. Also, reliability based preventive maintenance of each shovel and dumper system was calculated to improve their reliability about by 70%, 80% and 90%.

Chapter 8: In this chapter, Reliability Block Diagrams were drawn for each shovel and dumper and calculated the reliability of each system was calculated using failure rate of each subsystem. In this analysis, it is noticed that, effect of the failure of each subsystem on the permanence of shove-dumper combination i.e., Fussell-Vesely Importance is analyzed. However, based on the failures of the subsystem, mathematical models were developed for each shovel and dumper. The series-parallel configuration of shovel-dumper system was done to improve the reliability.

Chapter 9: In this chapter, number of failure states in each shovel and dumper and the overall reliability are analyzed. In this chapter, Transition diagram and mathematical model were developed for each shovel and dumper.

Chapter 10: In this chapter presents the conclusions of the overall research work, recommendation's and also presented the future work.

CHAPTER 2

LITERATURE REVIEW

A detailed literature survey was done to understand the approaches adopted by various researchers in the past to improve the performance and efficiency of shovel-dumper system in surface mines using analytical methods and mathematical models. In addition to shovel-dumper system, the performance and efficiency of few underground mine equipment's (LHD, SDL, hydraulic shovel and railway track etc.,) were discussed in literature review chapter.

2.1 Introduction

World mining today is at a particularly important stage in its development and a published by the British Geological Survey and the Natural Environment Research Council (Brown et al. 2006). This phase is characterized by a series of processes, such as: (i) Continuous increment in the tendency of prices of the majority of mineral commodities, (ii) Continuous booming demand for heavy mining equipment and permanent growth in production of large machinery for this type of industry. (iii) The strengthened position of surface mining in mining production as a whole.

The prices of mineral commodities have been growing for several/many years (Czaplicki 1992). The world market, especially the Chinese, calls for greater delivery of mine production (Czaplicki 2008; Weber 2005; White 2006). All these factors mean that the extraction of minerals is still a good business, although exploitation conditions are growing continuously more disadvantageous. So-called easy deposits which lies at shallow depth have been depleted, now is the time to reach deposits lying deeper or in more remote (Czaplicki 2008).

The majorities of metal ores are extracted by surface mining methods and account for approximately 80-90% of the total mineral production. The correct arrangement of machinery systems in mines and control of their operation are crucial. However, to improve mine output and to make it more beneficial, all the mechanisms influence on the course of the operation processes running in the mine need to be known. Generally, the extraction of mineral deposits from the surface by surface mining characterizes four types of mines. These are; (i) Alluvial mines, (ii) Quarries, (iii) Open cast or strip mines and (iv) Open-pit mines (Czaplicki 2008).

2.2 Sequence of Main Works in Surface Mine

At first, the places where the explosives will be loaded and then fired are determined. This concerns the blasting of both overburden and mineral. The Overburden must be removed in such a way that the extraction of the mineral can continue without interruption. To accomplish this preliminary operation, drillers are applied and loading equipment used to locate explosives in drilled holes. During blasting, the majority of operations in the mine are stopped. Loading is then performed by power shovels, and sometimes additionally by front-end loaders. These huge loading machines are the only ones that can cope successfully with this unfavourable broken rock (Czaplicki 2008).

The durability of shovel-truck sytem usually reaches 20–30 years, and the total mass up to more than a hundred ton. The steady-state availability usually varies between 0.80 and 0.90 for good quality machines. The time taken for material to be located from one bucket onto a truck is below 1 minute, and for a truck to be loaded usually about 2 to 3 minutes. The minimum number of buckets to fill a truck box is actually 3. Two buckets can also be applied, but if the bucket capacity is large enough to load a truck in 2 or 3 passes some disadvantageous effects may be inevitable. The first is the high possibility of frequent spillage of material around the truck being loaded. In the path, the capacity of the bucket of the shovels were 1 m^3 or 4.3 m^3 or 5 m^3 or 6.5 m^3 or 12 m^3. This leads to a longer duration of the truck work cycle because of the necessity of clean-up procedures in the loading area (Czaplicki 2008).

The second factor is the lower durability of some truck assemblies due to frequent, high-impact forces acting on the vehicle during loading. The lifetime of the box lining can also be reduced. Great power shovels require such an amount of money that they should be in operation 24 hours a day, 7 days a week. These huge units are either of the ‘rope’ unit is mechanical; but hydraulic machines of this kind are still growing and masses of 80–90 ton can currently be accommodated in their bucket. Hydraulic shovels have several significant merits compared to mechanical machines, so the hard competition is still on (Czaplicki 2008).

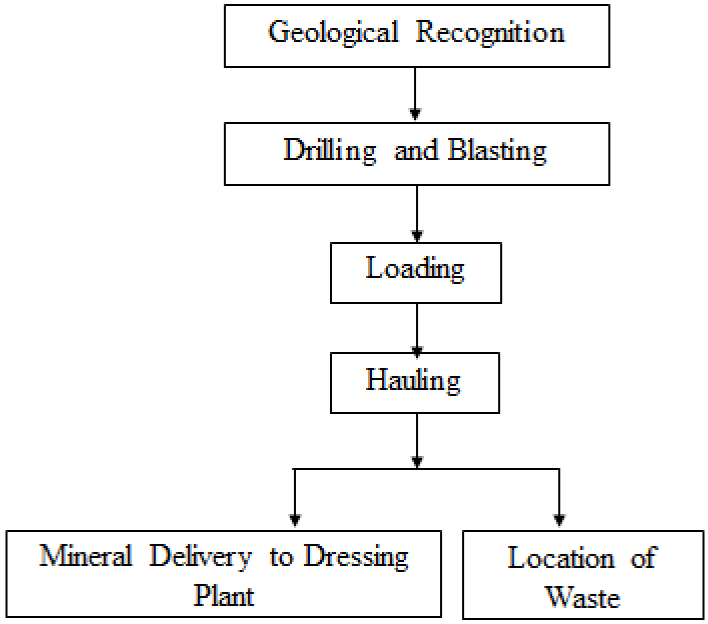


Figure 2.1 Sequence of main works in surface mine (Czaplicki 2008)

2.3 Brief Description of Shovel – Dumper System

One of the basic types of machinery systems in surface mining is the shovel-dumper system. A lot of problems are connected with control and monitoring of its operation, with appropriate selection of equipment in number and size and many other issues. Some of them have omitted spare unit application in the system; some have taken into account its existence neglecting the problem of proper determination of its size. The component of a typical shovel and dumper is shown in Figure 2.2 and 2.3 along with their subsystems. The descriptions of the major components of shovel and dumper are given below:

(i) Shovel: The Shovel (Hydraulic Excavators) (in Figure 2.2) is a heavy construction mining equipment used in the surface mines, consisting of a boom, dipper (or stick), bucket, engine, and electrical components. Majumdar (1995) said that it is an natural progression from the steam shovels and also movements and functions of a hydraulic shovel are accomplished through the use of hydraulic fluid with hydraulic cylinders and hydraulic motors. Also, the shovel is used for digging a deeper cut, loader and over casting and pulling back the spoil material and overburden removal in surface mine. The bucket which is mounted with sharp teeth cut the rock or mineral body and breaks them with the help of pressure provided by the hoist and crowd actions and also due to the linear actuation of hydraulic cylinders, their mode of operation is fundamentally different from cable-operated excavators (Majumdar 1995; Hadi Suryo, S and Bayuseno 2018). Generally, these machines consist of ten main subsystems, as shown in Figure 2.2.

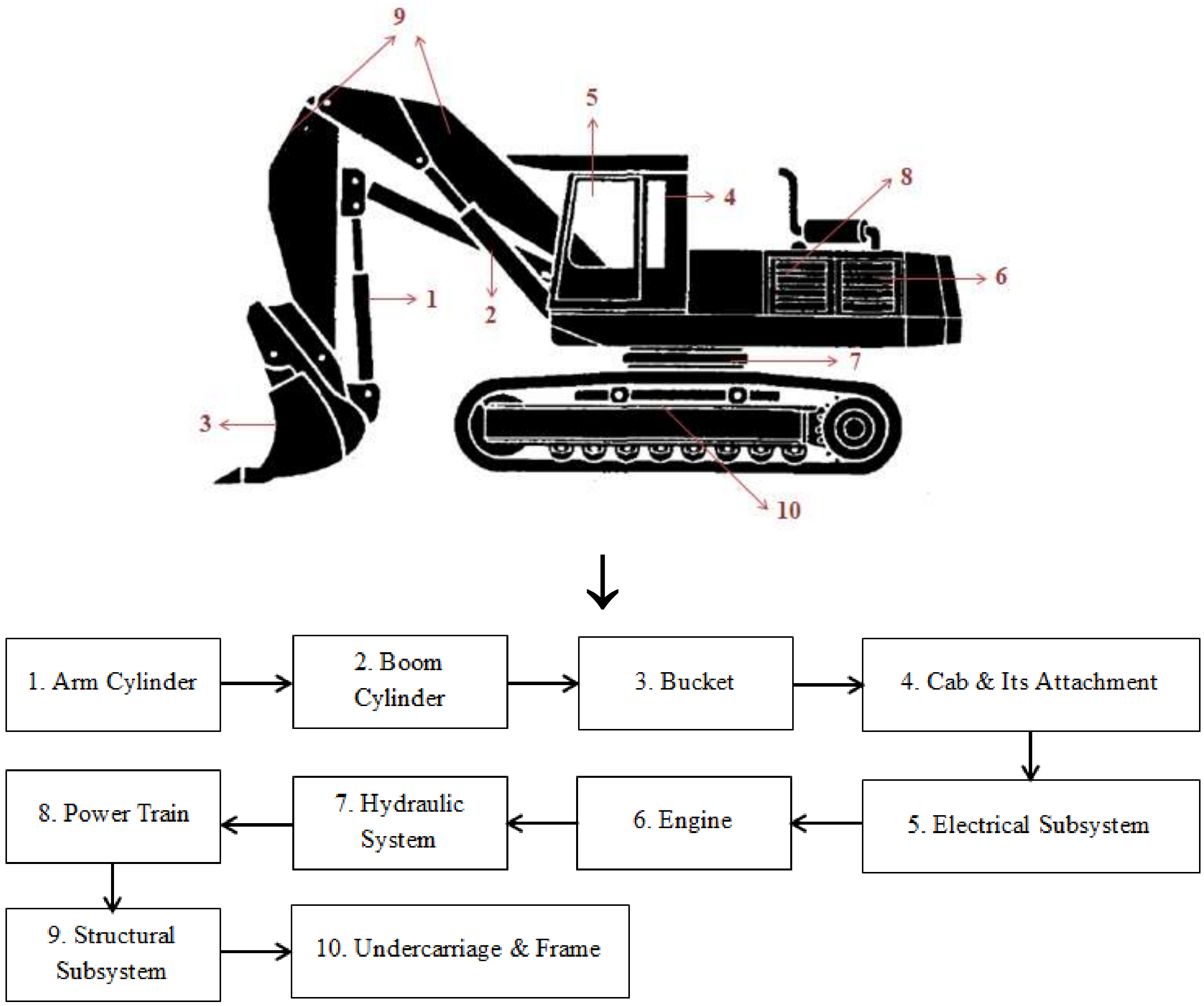


Figure 2.2 Shovel and its subsystems connected in series (Majumdar 1995)

(ii) Dumper: A dumper (also known as a dump truck) (Figure 2.3) is a truck used for transporting loose material (such as limestone, coal, ore particles). A typical dump truck is equipped with an open-box bed, which is hinged at the rear and equipped with hydraulic rams to lift the front, allowing the material in the bed to be deposited (dumped) on the ground behind the truck at the site of delivery. In the UK, Australia and India the term applies only to off-road construction plant such as mining (Dey et al. 1994; Kishorilal and Mukhopadhyay

2018). The dumper mainly consists of a braking system, deferential system, drive unit and transmission system etc.

A standard dump truck is a truck chassis with a dump body mounted to the chassis. The bed is raised by a vertical hydraulic ram mounted under the front of the body or a horizontal hydraulic ram and lever arrangement between the frame rails and the back of the bed is hinged at the back of the truck (Namata 2015). The tailgate can be configured to swing up on top hinges (and sometimes also to fold down on lower hinges) or it can be configured in the "High Lift Tailgate" format wherein pneumatic rams lift the gate open and up above the dump body. Generally, these machines divided into ten subsystems as shown in Figure 2.3.

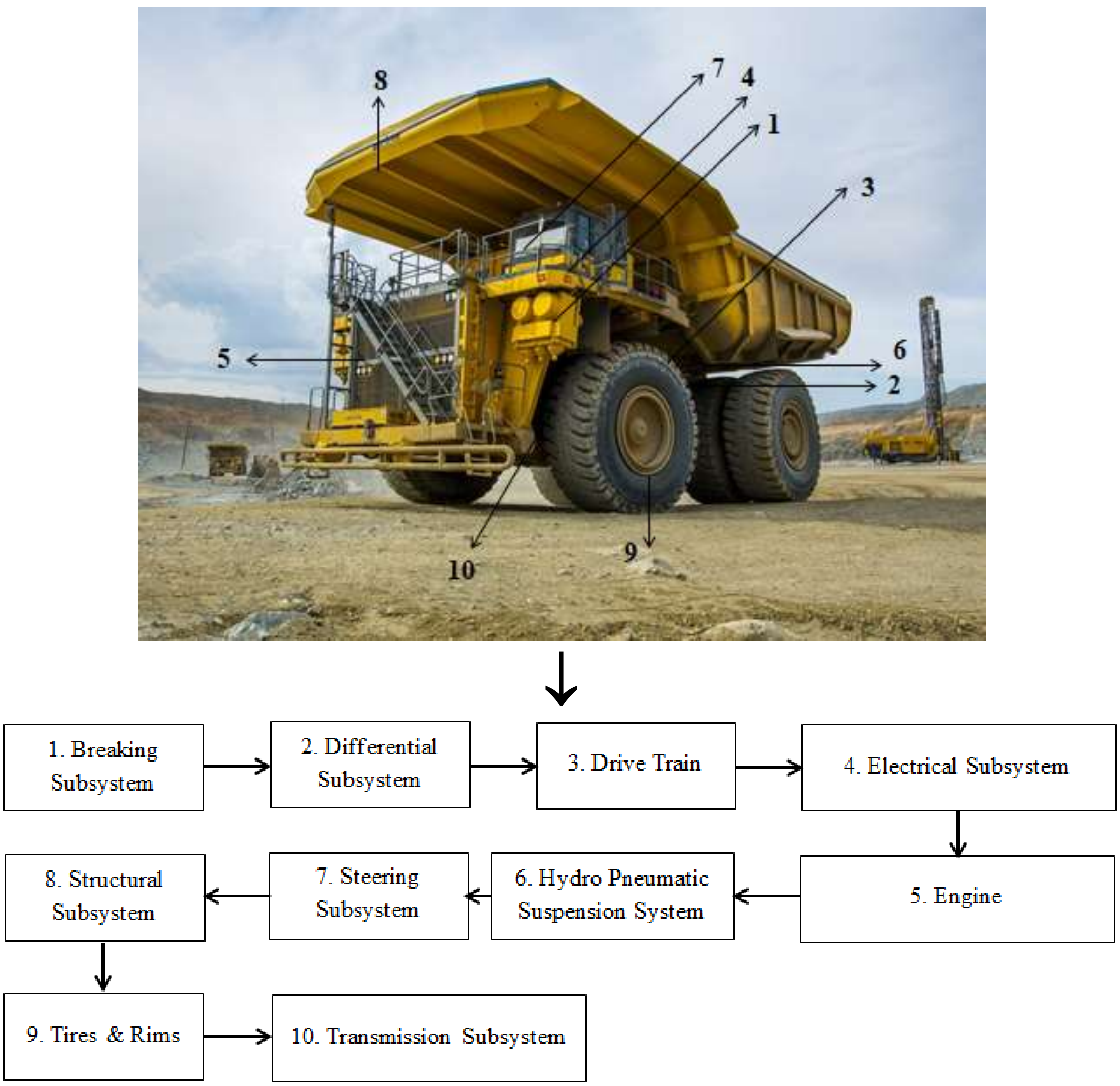


Figure 2.3 Dumper and its subsystems connected in series (Namata 2015)

2.4 RAM of Shovel-Dumper System

The study on RAM of the any mining equipment have become increasingly important in recent years due to the competitive environment and total operating and production costs in the mining sector (Barabady and Kumar 2008). Current technological systems in the mine are characterized by a high level of machinery and the need for studies on the availability and reliability of such systems is highly desirable (Barabady and Kumar 2008)

In Indian surface mines, the combination of shovel-dumper system plays the very important role and widely applied in surface mining (Czaplicki 1992). The shovel and dumper consist of many subsystems and many components (as mentioned in Figure 2.2 and 2.3). Each shovel and dumper subsystem affects the availability and reliability of the total production line. Therefore, each subsystem must be analyzed to determine how these subsystems affect the availability and reliability of the system as a whole (Kumar et al. 1989; Kishorilal and Mukhopadhyay 2018). To increase the reliability of any machine, it is necessary to study the reliability to determine the necessary improvements or modifications that must be implemented (Vayenas and Wu 2009). When these goals are met, they should be able to increase mining production and increase the availability and reliability of mining equipment.

The importance of high reliability is used in the operation of mobile mining equipment, both in surface and underground. It's a big problem, especially for automation applications, where the goal is to remove the operator from the device. More failures can be expected if a system has poor reliability (Hoseinie et al. 2012). Kishorilal and Mukhopadhyay (2018); Kumar and Klefsjo (1992) noted that the failure characteristics of the equipments are influenced by the reliability of the design. All failures have causes and effects. Therefore, after identification, defects can be designed or obtained by increasing maintainability. To obtain the investment of shovel and dumper in the mine, it is necessary to have a high reliability of the machine. For mining-related reasons, it is not always best to use shovels and dowels, but it may be necessary for safety reasons or to increase productivity. Dey et al. (1994); Kishorilal and Mukhopadhyay (2018) have analyzed the performance of shovel and dumper. But no studies have been done for different reliability methods such as RBD and Markov model and without considering the mine factors. Such a comparison between the reliability methods should be made between different mines since many mine factors e.g. the environment, cutting method, overall goals, maintenance policy, etc., affect the reliability and maintainability of shovel and dumper system (Gustafson 2011).

2.5 Probability and Statistics

Probability and statistics are two related topics, but they cover separate statistical disciplines. Statistical analysis often uses probability divisions, and both subjects are studied together. However, there are many probability theories, most of which are of mathematical interest and are not directly related to statistics.

In common use, the term "probability" is used to mean the possibility that a particular event (or set of events) will occur on a linear scale from 0 (impossibility) to 1 (certainty). It is displayed as a percentage between 0 and 100%. Probability-controlled event analysis is called statistics. Furthermore, statistics are rules that allow researchers to evaluate inferences derived from sample data. In practice, statistics refers to the scientific methods used to: (i) Collect data, (ii) Interpret and analyze data, and (iii) Evaluate the reliability of inferences based on sample data.

2.6 Probability Density Function (PDF)

A statistical measure that determines the probability distribution for a random variable and is often called f(x). Let x be a continuous random variable. So, the PDF function of X is the function f(x), such that for any two numbers a and b are given by equation (2.1) (Sahoo 2013).

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

That is, the probability that X takes the value in the interval (a, b) is the area over this interval and below the graph of the density function. The graph of f (x) often refers to the density curve. Since the probability cannot be negative and not greater than 1, the following two properties (given in equation 2.2 and equation 2.3) of the PDF are always true (Sahoo 2013; Xu et al. 2017).

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

$$f(x) \geq 0 \qquad (2.3)$$

2.6.1 Exponential distribution

The exponential distribution can be associated with component failure or maintenance (for sampling up to failure time and repair time, respectively). This distribution should be used to model the failure characteristics of non-aged compounds. The distribution represents a fixed failure rate (or repair rate). The following expression represents the use of division for failure (equations 2.4, 2.5, and 2.6). For repairs, the failure rate must be replaced by the repair rate and the failure time by the repair time (Mudholkar and Srivastava 1993; Sarhan and Apaloo 2013; Mustafa et al. 2018).

Probability density function *f (t)* $$f(t) = \lambda e^{-\lambda t} \qquad (2.4)$$

Unreliability *F (t):* $$F(t) = 1 - e^{-\lambda t} \qquad (2.5)$$

Failure rate λ *(t):* $$\lambda(t) = \frac{f(t)}{R(t)} = \lambda \qquad (2.6)$$

Where, R (t) - Function of reliability, t - time taken, e – Exponential

Because it has clear and simple expressions for the distribution function, this variable does not require the use of any type of table, since calculating the value of a distribution function and the probability of any interval is simple. The aspect that shows its density function is the part that can be seen in Figure 2.4. Other concerns of energy distribution are as follows with equation 2.7 (Andres and Ljubisa 2015):

$$p(t \in [t_1, t_1 + T]) = p(t \in [t_2, \mathrm{t}_2 + T]), \forall(t_1, t_2) \qquad (2.7)$$

Where, P - Probability density function, T – Total working hours in hrs, t_1 and t_2 – Time intervals

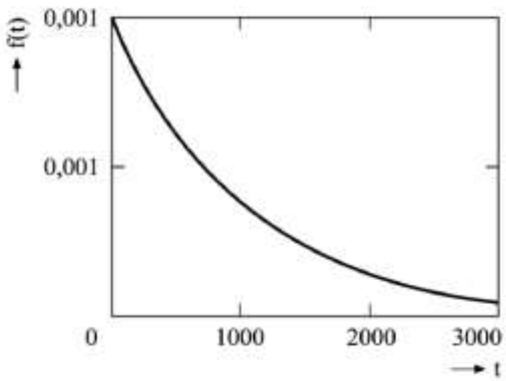


Figure 2.4 Exponential distribution: density function (Andres and Ljubisa 2015)

2.6.2. One parameter Weibull distribution

The Weibull distribution is used to model the failure characteristics of components with time-dependent failure rates. The most common use is to model the old characteristics of mechanical components. The 1-Parameter Weibull calculation method requires the user to specify the distribution form parameters. By fitting the Weibull distribution to historical data, a different reliability of the characteristic life parameters will obtain for the best fit (Xu et al. 2017; Mudholkar and Srivastava 1993; Mustafaet et al. 2018; Sarhan and Apaloo 2013).

2.6.3 Two parameter Weibull distribution

The expressions for the 2-parameter Weibull are identical to the expression given above for the 1-parameter Weibull method. The only difference is that the user does not specify the value of the shape parameter. The program will assign the shape parameter as well as the characteristic life when fitting the distribution to the data. The appropriate substitutions to obtain the other forms, such as the 2-parameter form when $\gamma = 0$ (Xu et al. 2017; Mudholkar and Srivastava 1993; Mustafaet al. 2018; Sarhan and Apaloo 2013).

2.6.4 Three parameter Weibull distribution

The Weibull distribution is widely used in reliability analysis and life data because of its flexibility. Depending on the parameter values, the Weibull distribution can be used to model different life behaviors. How the values of the shape parameter β, the scale parameter η and γ are the location parameter affects such distribution characteristics as the shape of the curve, the reliability and the failure rate will be examined. The general equation for the classification of the parameters of three waves is given by equations 2.8, 2.9 and 2.10 (Xu et al. 2017; Mudholkar and Srivastava 1993; Mustafaet et al. 2018; Sarhan and Apaloo 2013; Andres and Ljubisa 2015):

Probability density function *f (t)*: $$f(t) = \frac{\beta(t-\gamma)^{\beta-1}}{\eta^{\beta}} e^{-(\frac{t-\gamma}{\eta})^{\beta}} \quad (2.8)$$

Unreliability *F (t):* $$F(t) = 1 - e^{-(\frac{t-\lambda}{\eta})^{\beta}} \quad (2.9)$$

Failure rate λ *(t)*: $$\lambda(t) = \frac{\beta(t-\gamma)^{\beta-1}}{\eta^{\beta}} \quad (2.10)$$

Where, β is the shape parameter, also known as the Weibull slope, η is the scale parameter and γ is the location parameter

The minimum life δ is an age that will surely be reached by the elements studied. Often, as discussed, the minimum life takes the value zero. The characteristic life θ is an age such that the probability that it is exceeded is 36.79% or, which is equivalent, in such a way that 63.21% of the elements fail before reaching it. Although the characteristic life is not the average of the Weibull distribution, it can be interpreted as an approximate position indicator (In exponential distribution the probability of exceeding the mean is precisely 36.79%). Finally, the shape parameter β describes the shape of the distribution and the key to understanding the behavior of the variable life or duration of the elements studied. What the density function of this Weibull variable looks like depends on the value of its parameters. Figure 2.5 shows the form of the density function for different values of β.

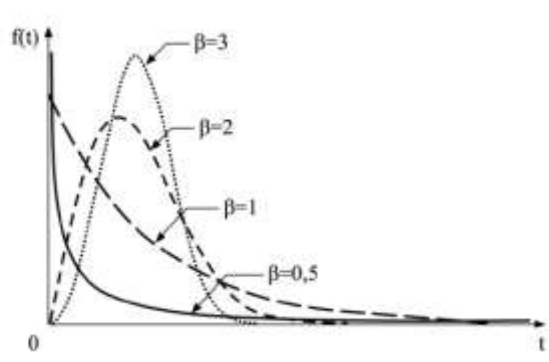


Figure 2.5 Weibull distributions: density functions (Andres and Ljubisa 2015):

2.6.5 Cumulative distribution function (CDF)

The function that gives the probability of a random variable is less than or equal to the independent variable of the function. For the random variable X, CDF is the function F(x) defined by equation 2.11 (Andres and Ljubisa 2015).

$$F(x) = P(X \le x) = \int_0^x f(x)dx \tag{2.11}$$

Where *X* is the random variable, which is the sum or integral of the PDF of the distribution and *x* is the independent variable.

2.7 Reliability

The term reliability is defined as "the ability of an item to perform a required function under given conditions for a given time interval" (Cassady et al. 2001; Taheri and Bazzazi 2017; Andres and Ljubisa 2015). Reliability can also be defined as the probability that an item (component, subsystem, or system) or will function properly for a specific period of time (design life) under specific conditions of use (environmental and operating conditions) without fail (Cassady et al. 2001). In mathematical terms, the failure time T of an element is defined as a continuous random variable. Reliability, which is a function of time t, will be expressed as the probability that the failure time T is greater than the operating time t. This means that reliability is the probability that the failure did not occur at t and is given by equation 2.12 (Anonymous 2006).

$$R(t) = P(T > t), \text{ Where, } R(0) = 1 \text{ and } R(t) \ge 0 \tag{2.12}$$

A reliable function can be derived from the incremental distribution function F (x). In reliability, 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 by F (t) and combined with the fact that the area under the PDF is always equal to one, the reliability function is shown:

$$R(t) = P(T > t) = 1 - F(t) \tag{2.13}$$

The relation between the CDF and the PDF is given as

$$F(t) = \int_0^t f(t)dt \quad (2.14)$$

And reliability function is obtained as:

$$R(t) = 1 - \int_0^t f(t)dt \quad (2.15)$$

$$R(t) = \int_t^\infty f(t)dt \quad (2.16)$$

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

The unreliability, or in other words, the probability of a failure occurring is the opposite and is defined as the probability that the failure time T is equal to and less than the operating time t. This is the same as CDF and is shown:

$$F(t) = P(T \leq t) \quad (2.17)$$

$$F(t) = \int_0^t f(t)dt \quad (2.18)$$

Model-based methods can be further subdivided into experimental and analytical methods, and both require system models that are constructed in terms of random variables for the state of the underlying entity (Wang et at. 2019; Wang and Chen 2009; Mani and Mahendran 2017). The simulation method uses the probability distribution function for device failures and repair actions to simulate the detailed dynamic behavior of the system and evaluate the necessary measures. The classification of reliability analysis methods is given in Figure 2.6.

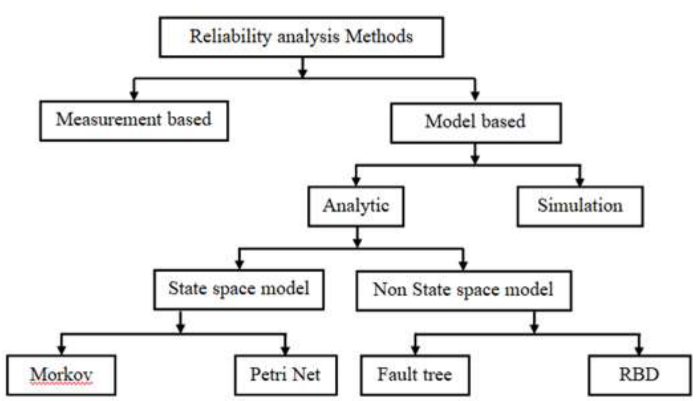


Figure 2.6 Classifications of reliability analysis methods (Goel 2004)

2.7.1 Analytical methods

Analytical methods were used to calculate the reliability and the available measures of the system using structural results of the applied probability theory. Various analytical methods have been developed that can be broadly classified into state and out-of-state spatial modeling techniques (Signoret et al. 2013; Goel 2004). The choice of a suitable modeling technique to describe the behavior of a system depends on factors such as: (i) Measures of interest (stability or dependence on time, reliability, availability, maintainability, (ii) Level of detail and the complexity of a given system (Structure size, etc.), (iii) Tools available to clarify and resolve models and (iv) Availability and quality of data.

(a) State-space methods:

The non-state models described above cannot handle complex situations more easily, such as failures/dependencies, maintenance of joint repair facilities, different types of maintenance for different units with different effects and resource requirements. In such cases, more detailed models such as the Markov chain model and the pure model can be used.

Markov model: The Markov model provides a powerful modelling and analysis technique with strong applications in time-based reliability and availability analysis. The reliability/availability behavior of a system is represented using a state-transition diagram, which consists of a set of discrete states that the system can be in, and defines the speed at which transitions between these states take place. The transition from one state to the next state depends only on the current state irrespective of how the system has arrived at that state. Markov models provide greater modelling flexibility with some of the advanced features such as (i) Ability to model component dependency issue such as cold or warm standby, (ii) An ability to model sequence dependent behavior and (iii) An ability to handle different types of maintenance (Goel 2004).

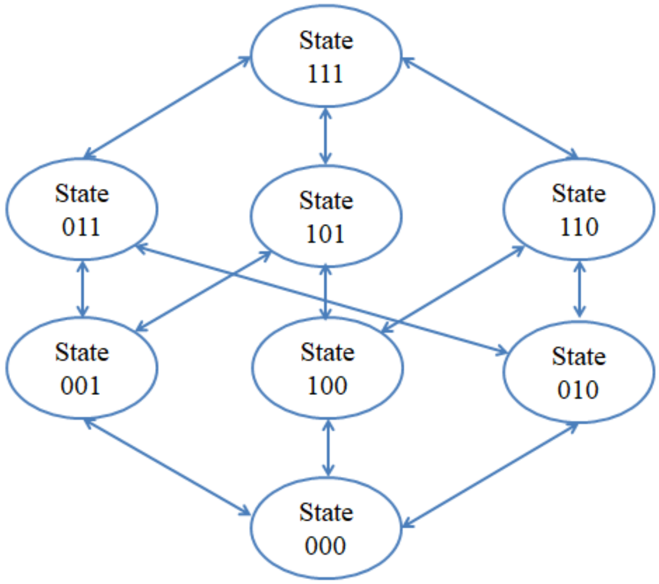


Figure 2.7 Markov state transition model for an illustrative example (Goel 2004).

The state transition diagram for the demonstrative example is shown in Figure 2.7. The states are described in the example by a combination of the numbers 0 and 1, where 1 represents the "up" state and 0 represents the "down" state. For example, state (101) describes the state of the system in which two reactors fail. Also, Markov modelling is an explosion of the number of states even when dealing with relatively small systems. However, recently, Knegtering and Brombacher (2000) proposed a new technique to reduce the number of Markov states by combining the practical benefits of a reliable block diagram. Work published by Sharma and Garg (2011); Singh et al. (1990); Gustafson et al. (2014) on the available analysis of the urea fertilizer plant, the mining industry provides an example of the application of the Mark model in process design.

A simpler Markov model can be used to calculate the probability of P_I, as shown in Figure 2.8. The simplified model not only includes fault transformations, but also repairs processes (λ_i). The probability of a Markov state 4 corresponds to a P_{II}. The probabilities of P_{II} and P_{III} are calculated in the same way. Implementation of probability assumptions for P_I, P_{II}, P_{III} and S_{system} has failed. P_I is represented by sectors 5 and 8, P_{II} by sectors 6 and 8, and P_{III} by sectors 7 and 8. S_{system} is reflected by sectors 5, 6, 7 and 8 is given by equation 2.19. The state numbers in the Venn diagram correspond to the state numbers of the complete Markov model shown in Figure 2.8. Immediately it will be proved that the combination of the occurrence of the three faults is also represented and therefore it is calculated in the eighth sector without having to create this state in the micro Markov models (although mainly negligent). Furthermore, Knegtering and Brombacher (2000) reported that computer programmers were designed to study the effectiveness of various maintenance and repair parameters on the probability of state stability and productivity of mining equipment such as LHD using five-state Markov model.

$$P_{Systemhasfailed} = 1 - (1 - P_I) \times (1 - P_{II}) \times (1 - P_{III}) \tag{2.19}$$

Where, P_I = The probability of a failure between U and V

P_{II} = The probability of a failure between W and X

P_{III} = The probability of a failure between Y and Z

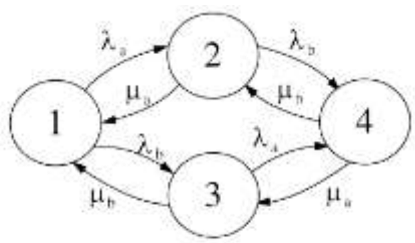


Figure 2.8 Simplified Markov model (Knegtering and Brombacher 2000)

Petri net: Petri net of different types can be used to assess the reliability and availability measurements for a system at the design stage. A Petri net is a directed-graph consisting of places, transitions, arcs and tokens. The Tokens are stored in place and moved from place to place along the arc through the transition. Marking is the job of the tokens to the place, and these can change during the execution of Petri nets. If the transition time is strictly timed, the Petri nets are called stochastic Petri net (SPN). If the variables are distributed exponentially, it is possible to estimate the probability statistics that are the same as the Markov chains models. A pure Petri diagram for the display example is shown in Figure 2.9, which shows the initial state of the system (Goel 2004)

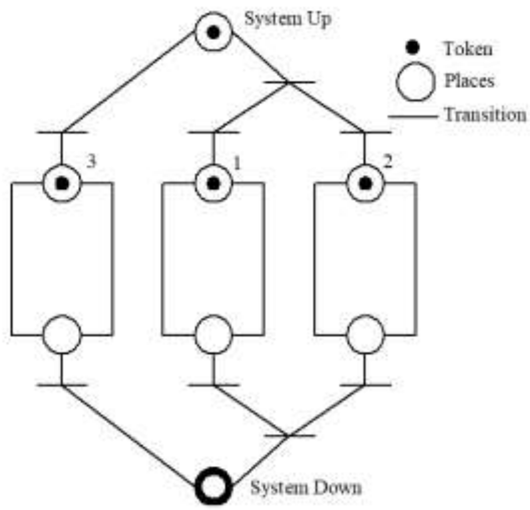


Figure 2.9 Petri net model (Goel 2004)

(b) Non-state space methods:

As the name suggests, non-state space models can be solved without generating the underlying state space. These models can be easily used for solving systems with hundreds of components. These models can be applied to fairly large systems to provide performance measures such as a system's steady-state availability, reliability and the mean time between failures (MTBF). The key assumptions used in non-state space models are statistically independent failures and independent repair for components. Two prominent non-state modelling techniques used to evaluate system availability are: the Fault Tree (FT) and Reliability Block Diagrams (RBD).

Fault tree (FT): A fault tree is a symbolizes the logical relationship between events and can be used to represent a combination of events that will lead to the failure of a system called a top event. The fault tree model for the display example is shown in Figure 2.10. In Figure 2.10, the top event "A" represents the total system failure that would occur if event E1 (failure of reactor 1 (E3) and reactor 2 (E4)) or event E 2 (failure of compressor) occurs (Kumar and Gandhi 2018); Mani and Mahendran 2017; Goel 2004). The traditional fault tree, when used as a reliability-availability analysis tool is its capacity for handling complicated maintenance procedures which are best handled by state-space methods. However, some recent developments, such as dynamic fault trees, which can be model-dependent events, have improved the capabilities of the fault trees (Baig et al. 2013; Samantaet al. 2002). There are several examples available in the literature of the successful application of fault tree analysis to industrial process systems. For example, fault trees analysis is often used for the reliable analysis of desalination plant (Hajeeh and Chaudhuri 2000; Badida et al. 2019; Kutbiet al. 1981; Goel 2004).

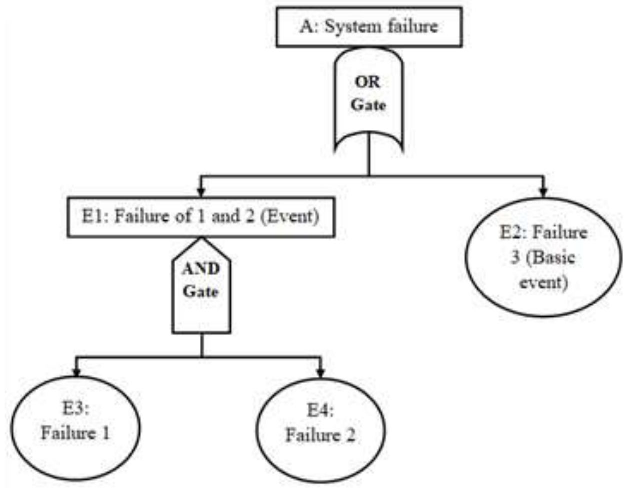


Figure 2.10 Fault tree model (Goel 2004)

Reliability block diagrams (RBD's): The RBD is used to assess the characteristics related to various failures, such as the reliability, availability and maintenance of various engineering systems (Billinton and Allan 1992; Lin, et al. 2010; Huffman and Antelme 2009; Boyd and Locurto 1986). The RBD is primarily a graphical structure containing Blocks and connectors (lines) that represent the functional behavior of the system components and their respective interactions. For example, when evaluating the reliability of computational software, blocks can represent computational elements with a failure rate and connectors between them can be used to describe the various alternatives required to perform satisfactory calculations using the provided software (Abd-Allah 1997).

It is a basic reliability model that is used for example in the standard. Within any module that is not itself fault tolerant, it can be assumed that failure of any of its components may cause a system failure. Such an arrangement is shown in Figure 2.11 (Ahmed and Tahar 2016; Rani 2011).

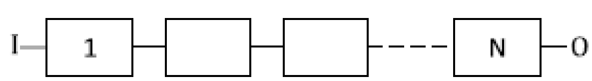


Figure 2.11 RBD model in series (Ahmed et al. 2016; Rani 2011)

Here, the blocks describe the various component or parts of the designed system. It is not the aim of the individual blocks to physical interconnection of the system components but to show the dependency of their reliability properties. As a failure of any of the blocks will result in overall failure, the failure rate of a serial model is equal to the sum of the failure rates of the individual blocks. If a system contains N components, then it may be assumed that the failure of various components is independent. The system's failure rate $(-\lambda)$ during its constant failure rate period, is given by equation 2.20 (Abd-Allah 1997).

$$\lambda = \lambda_1 + \lambda_2 + ... + \lambda_N \tag{2.20}$$

Where λ_ι is the constant failure rate of the i^{th} component? This expression can be rewritten as

$$\lambda = \sum_{i=1}^{N} \lambda_i \tag{2.21}$$

The reliability of the arrangement may also be expressed in terms of the reliability of the components. If R_i (t) is the reliability of the i^{th} component in the system, then the overall system reliability R(t) is given by the expression

$$R(t) = R_1(t) + R_2(t)......R_N(t) \tag{2.22}$$

It may be written as

$$R(t) = \sum_{i=1}^{N} R_i(t) \tag{2.23}$$

$R_1(t)$ – Reliability of each system and n^{th} order, R(t) – Reliability of overall system

In systems that contain redundancy, failure of one of the modules or one of the components may not result in failure of the whole system or subsystem. Such an arrangement is described as a parallel system and is shown in Figure 2.12 (Ahmed et al. 2016; Rani 2011).

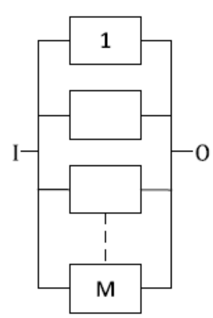


Figure 2.12 RBD model in parallel (Ahmed et al. 2016; Rani 2011)

In this arrangement, it is assumed that the system will remain operational provided that at least one of the parallel blocks is functioning correctly. The reliability of a parallel system is determined by considering the probability of failure, the first of an individual block, and then of the complete system. As the reliability of a block R(t) is the probability of that block functioning correctly for a period of time t, then [1-R(t)] must be the probability of it failing within that time. The quantity [1-R(t)] is referred to as the unreliability of the component and is given the symbol Q(t).

If a system contains N parallel blocks, then the probability of all the units failing independently will be the product of the probabilities of each unit failing individually. Thus, the probability of failure of the system is given by (Boyd and Locurto 1986)

$$Q(t) = [1 - R_1(t)][1 - R_2(t)].......[1 - R_N(t)] \tag{2.24}$$

Where, $R_i(t)$ is the reliability of the i^{th} block and Q(t) is unreliability of the system. The reliability of the system is therefore

$$R(t) = 1 - Q(t) = 1 - [1 - R_1(t)][1 - R_2(t)].......[1 - R_N(t)] \tag{2.25}$$

Or simply

$$R(t) = 1 - \sum_{i=1}^{N} [1 - R_i(t)] \tag{2.26}$$

2.8 Availability

The availability is defined as "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" (Anonymous 2006). 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 way (Dhillon 2008; Mazzeo et al. 2018). The availability is given by equation 2.27.

$$Availability = \frac{MTBF}{MTBF + MTTR} \tag{2.27}$$

Where, MTBF – Mean time between failure, MTTR – Mean time to repair

2.9 Maintainability

The maintainability is defined as “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 (Anonymous 2006). 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 (Dhillon 2008; Mazzeo et al. 2018).

In mathematical terms, the time to repair of an item is defined as a continuous random variable. This random variable will have a probability density function like the reliability function described already. However, maintainability addresses the probability that the repair has happened, and therefore the maintainability, which is a function of time *t*, is expressed as equation 2.28 (Dhillon 2008; Mazzeo et al. 2018).

$$M(t) = P(T' \leq t) = F'(t) \tag{2.28}$$

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, this mean that there is an 80% probability that the system or component will be restored or repaired within a day. The PDF for the maintainability is denoted f(t), then the maintainability function M(t) can be further expressed as equation 2.30 (Dhillon 2008; Mazzeo et al. 2018).

$$M(t) = 1 - e^{-(\frac{t}{MTTR})} \tag{2.29}$$

Where, M (t) is maintainability function, t is time and MTTR is Mean time to repair.

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 are performed randomly as failure times are not possible to know in advance.

- Preventive maintenance is the maintenance actions performed before the 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 has 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 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.

2.10 Hazard rate or Failure 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* (Xu et al. 2017). This probability can be expressed as the following:

$$h(t)dt = \frac{f(t)dt}{R(t)} \tag{2.30}$$

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 (Xu et al. 2017). 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, PDF, and reliability function is given as the following (Xie et al. 2002; Xie and Lai 1996).

$$h(t) = \frac{f(t)}{R(t)} \tag{2.31}$$

The failure rate λ (t) of almost any type of elements varies in function of the time. Frequently, during the first period of life of the elements, the failure rate will be diminishing (early failures period) until it reaches a value and the failure rate is maintained sensibly constant (accidental failures period) and that it is the zone called the useful life of the system. Finally, from a given age, the failure rate grows up, generally of a very rapid manner (period of failures by obsolescence or wear out period). In Figure 2.13 is the curve of the failure rate is shown (Andres and Ljubisa 2015).

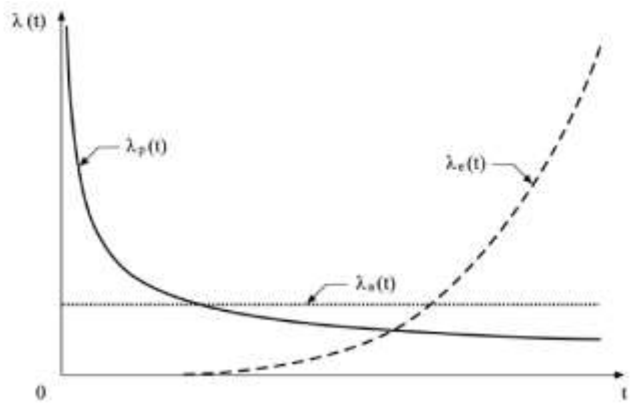


Figure 2.13 Time dependent failure rate function (Andres and Ljubisa 2015)

The early failures are those which are produced in the initial period of the system operation, generally in the first minutes or hours of operation. They are failures caused by design or manufacture mistakes and once repaired do not occur again in the same element. The early failures can be avoided submitting to the elements to Burn in tests: in occasions is accomplished a test in the 100% of the elements to simulate the operation and to eliminate this type of failures. The elimination of early failures is necessary to obtain a good reliability (Andres and Ljubisa 2015).

The useful life period is characterized by having a constant failures rate and by the absolute predominance of the accidental or random failures, caused by many different and unexpected circumstances (not by an improper use neither by manufacture defects). Enter in this category of accidental failures those caused by occasional efforts, mistakes of operation of the user and, in general, to the unpredictable situations not associated with the time of use or with the age. The accidental failures can be controlled with a good operation procedure and with adequate preventive maintenance (Andres and Ljubisa 2015).

The failures by obsolescence, or wear out failures, are those associated with failure mechanisms due to the use or the age of the element: fatigue of the material, degradation of the elements, insulating, etc., that are originated gradually with the operation of the elements. The failure rate can be reduced with maintenance plans that avoid the depletion of the elements. Consequently, in a system, after the elements have operated correctly during a time b, if the used elements are not replaced by new ones, free of early failures, the service will be made insecure and the reliability will descend to dangerous values. In general, in the obsolescence zone, the growth speed of the failure rate depends on the regime of use of the element in its period of useful life (Andres and Ljubisa 2015).

Some of the research work had undergone on the reliability analysis of the different mining equipment's in surface and underground mine, whereas major research work carried out regarding failure analysis of the critical parts in heavy earth moving machineries in surface and underground mine using the reliability analysis. A brief summary of the related research work carried out by different researchers is discussed below.

Kumar et al. (1989) studied reliability investigation for a fleet of load haul dump machine in a Swedish mine. According to this paper, due to random equipment failure maintenance and operational reliability of LHD is less. It has been estimated that, operational reliability and optimal preventive maintenance on one year the failure data of LHD machines are analyzed using the graphical technique of total time on test (TTT) and also analytical methods like Kolmogorov-Smirnov test and maximum likelihood estimation are used in this analysis. In this paper, it has been studied that, the importance of testing the reliability data for the presence of trends and serial correlation is also emphasized. It is concluded that, preventive maintenance of the engines of LHD machines could reduce the maintenance costs. Also, if data are available in sufficient quantity, decisions about the preventive maintenance can be taken. For mining industry, this type of studies can be of great help in reducing the steeply increasing cost of maintenance. Such studies are important keeping in view the present trends of automation in mines.

Vagenas et al. (1994) carried out on analysis of truck maintenance characteristics in a Swedish open pit mine. It was carried out by, the deployed graphical, analytical and statistical tools in RAM analysis to study the failure and repair characteristic of the system and its subsystems. They further used these tools for enhancing the availability of mine trucks.

Xie and Lai (1996) carried out reliability analysis using an additive Weibull model with bathtub–shaped failure rate function. It has been concluded that life time distribution of the many components usually having bathtub shaped failure rate. It has been found that failure rate of the any component is high at the beginning due to design and manufacturing defects and decrease towards the constant failure rate. After reaching certain working hours, the component enters into increasing the failure rate due to wearing and caused by component fatigue. I has been drawn bathtub curve with two parameter Weibull distribution by using the conventional statistical estimation techniques i.e., numerical analysis using a set of real life data for the different models.

Vagenas et al. (1997) studied methodology for maintenance analysis of mining equipment. It has been studied that, maintenance based reliability of three LHD and its subsystems such as bucket, electrical systems, drivelines, hydraulic, engine, brakes and etc., in underground hard rock mine based on 100 working hours of each system. In graphical reliability maintenance analysis, TBF and TTR were determined each type of failure using the combination of graphical, statistical and analytical techniques. Using some software packages it has calculated MTBF, MTTR. It’s also analyzed three different types of theoretical probability distribution which are considered in failure analysis of the LHD such as Weibull, Lognormal and Exponential distribution. These theoretical probability distributions model has to be goodness of the fit to time to repair data and/or time between failure data by using Chi-Squared test and Kolmogorov-Smirnov (K-S) test.

Roy et al. (2001) carried out a maintainability and reliability analysis of a fleet of shovels. As per their study, they stated that reliability and maintainability of the HEMM jointly affects the availability and production of four electrical shovels at Rajarappa opencast project of Central Coalfield Ltd (Coal India, Ltd.). It has been found the nature of the failure parts, repair pattern by identifying the fault and critical parts of the shovel based on the reliability analysis. The collected failure data (TTF) and repair data (TTR) are subjected to reliability analysis based on Weibull distribution using Stat graphics software.

Xie et al. (2002) carried out a modified Weibull extension with bathtub shaped failure rate function. This paper presents that, model with bathtub shaped failure rate function are useful in reliability analysis related to decision making and cost analysis. It has been carried out new model which is useful for calculating this type of the failure rate function and also it has seen as generalization of the new Weibull distribution using the parameter estimation methods for 50 electronic components and data of these components has been shown from the Total-Time-on-Test (TTT). It has been analyzed that, failure rate of the components depends on the shape parameter β (When $\beta \geq 1$ increasing failure rate, $\beta \leq$ decreasing failure rate and β = constant failure rate). Also it has founded that, mathematical model such as $y = 0532x - 2.5039$ using the graphical model and maximum like hood estimation.

Vagenas et al. (2003) studied applying a maintenance methodology for excavation reliability. As per their study, reliability analysis is not only for the machine system but also applies to the excavation process. They suggested that maintenance methodology of the excavation process in underground mine based on reliability analysis by considering the factors like, ground condition, blasting, corrosion of the ground support system and structural stability of the ground. The reliability analysis approach used a graphical and statistical methodology to fit a theoretical probability distribution to collected maintenance data for prediction of the future failure trends by using the Expert-fit software. It is concluded that maintenance and reliability studies should be an integral part of mine engineering management for effective utilization of resources and for enhanced safety and competitiveness.

Samanta et al. (2004) studied reliability modeling and performance analysis of an LHD system in mining. It has been done, reliability, availability and maintainability of the LHD in underground coal mine with failure and repair data by Markov modeling. It has been discussed that, LHD plays very important role for the loading of coal on a chain or belt conveyor therefore, analysis of the reliability, availability and maintenance of each sub systems of the LHD is required to increase the performance of the LHD. Also it has been shown that, sub systems of the LHD is drive unit, bucket, transmission hydraulic sub system, these subsystems are shown by using the RBD.

Wang et al. (2004) studied reliability block diagram simulation techniques applied to the IEEE Std. 493 standard networks. It has been studied on the determination of the reliability and availability of industrial and commercial power system. There is a recognized need in the energy industry to identify and use standard equipment or instrument sets to analyze the reliability of electrical systems. In this it has described the simulation method through RBD applied to the Gold Book standard network. The reliability indices of the load points were analyzed and compared with techniques obtained from other techniques in the series to determine precision via RBD.

Faraci (2006) explained calculation of failure rates of series/parallel networks. This study was carried out by the failure rate of series and parallel reliability network using the reliability Toolkit (commercial Practice Edition published by the system reliability center as a guide). It has been provided that, examples of the correct approach and approximately the percent error one can expect when failure rate is calculated erroneously. Also it has concluded that, the larger network, the larger potential error when oversimplified approaches were used to calculate the reliability of the any complex network.

Torell and Avelar (2004) carried out mean time between failures: explanation and standards. It has been conclude that basic parameter of the reliability engineering to construct the bathtub curve and also this paper said that reliability prediction methods. This paper explained that, the underlying complexity and misconception of MTBF and the methods availability for estimating the reliability.

Barabady and Kumar (2008) carried out reliability analysis of mining equipment: a case study of a crushing plant at Jajarm Bauxite Iron Mine. It has been analyzed that, performance of crushing plant, based on the reliability engineering, operating environment, maintenance efficiency and operational process to calculate the life time of the system. It has been calculated that, the parameters of the some probability distribution, such as Weibull, Exponential and Normal distribution have been estimated by using Reliasoft Wiebull+$^{+6}$ software. Also it has been analyzed that, field data by using the pareto chart of data, trend test and serial correction, analysis of trend-free data and analysis of data with a trend to calculate the time between failure, time to repair. It has been concluded that, maintenance cost is major part of the total costs of all manufacturing or production plants about 15% to 60% and time interval for different levels of reliability 0.9, 0.75 and 0.5 for 19.4.

Vayenas and Wu (2009) carried out maintenance and reliability analysis of a fleet of load-haul-dump vehicles in an underground hard rock mine. It has been estimated that evaluation of reliability and maintenance characteristics of the 13 LHD's (Scoop Trams). It has provided that statistical analysis of the causes for equipment failure and breakdowns using the graphical method at underground hard rock mine in the Sudbury area at Ontario, Canada. Here it has been shown that, reliability based approach such as basic maintenance approach to determine the causes of failure and reliability based analysis to indicate the machine future operating characteristics by using the probability distribution modeling techniques. In this paper, data table has been developed for the parameters such as repair frequency, total repair hours, percentage of the total repair for each failure of LHD. It was found that MM (mechanical breakdown) and MP (planned maintenance) consume the most repair time and repair frequency of most of the LHD. The Exponential probability distribution and the lognormal probability distribution fit the data of most of the LHD. The mechanical availability for most of the LHD's from 42% to 66%.

Behera et al. (2011) investigated reliability investigation for a fleet of load haul dump machines in a mine. It has been carried out the operational reliability analysis, improved in design to enhance the reliability and preventive maintenance of the LHD in Coal India Mine situated in Nagpur. It has been analyzed that, the time between failures (TBF) of sub systems of the LHD such as engine, transmission, hydraulic, brakes and others for period for two years. In this, several statistical distributions and parameters by using the maximum like hood method were calculated. Also it has been shown that, exponential distribution, Weibull distribution and lognormal distribution were tried to describe the nature of the TBF distribution by using the Kolmogorov-Smirnov (K-S) test and it is used as a measure of good of fit of the different distribution. It has been conclude that, shape parameter in Weibull has 0.86 which being less than one shown decreasing the failure rate and shape parameter of the sub system engine of 1.35 which being greater than one shown the increasing the failure rate therefore preventive maintenance has economic.

Rhayma et al. (2013) studied reliability analysis of maintenance operations for railway tracks. It has been studied that, reliability analysis in railway truck adapted based on the biometrical and mechanical parameters of the track. Also, numerical results showed for reliability analysis of different maintenance operations. It has done that, deterministic modeling based on the finite element analysis by considering the young's modulus, poisons ratio and thickness, these above mentioned parameters are considered based on the sub systems of the railway track such as non-compacted ballast (E=20 MPa, γ=0.3 and h=0.21 m), rails (E=2×E4MPa, γ=0.3 and h=UIC60 profile), pads (E=40Mpa, γ=0.3 and h=9×E3 m) and sleepers (E=3×E4 MPa, γ=0.25 and 0.21m) to analyze the reliability of maintenance. Also it has done R^2 valued probability model having the control variables associated with the observation Z=(Z(t), t€R_+) of the response process Q=(Q(t) t€R_+). It has shown that, methodology to optimize the maintenance operations in railway department using the reliability analysis is very easy.

Rahimdel et al. (2013) investigated on reliability based maintenance scheduling of hydraulic system of rotary drilling machine. According to the authors hydraulic system in drilling machines has critical and most important system, so that any problem leads in power system and drilling machine operation. Since the failure rate cannot be prevented entirely, therefore reliability analysis is most important concept to minimize the failure probability of the drilling machineries. In this paper failure data analysis of the drilling machineries has done by using the time between the failures (TBF) of the machine. Also, it has done best fitting curve for particular sub system of the system and also it has been calculated by using the MIL-HDBK-189 Test (Military Handbook, 1981). In the reliability analysis system, failure rate of the machine follows the shape of the bathtub curve with three different phases.

Mouli et al. (2014) studied reliability modeling and performance analysis of dumper systems in mining by KME method. It has been studied that RAM of 12 to 15 years old 36T dumper with failure and repair data by using the Kaplan – Meir Estimation (KME) in OCP-III of Ramagundam. It has been considered that, filed data is analyzed both analytical method and graphical method. In graphical method, cumulative plot test and serial correlation determine the presence of trend and further analysis by considering the one of the most popular and commonly used power law process i.e., non-homogenous poisson process (NHPP). As per the paper, failure rate of the dumpers high and low availability than other equipment's due to low maintainability and trend analysis shown that, two dumpers are not showing a trend and KME method has proven that both dumpers are less reliability.

Fan and Fan (2015) carried out reliability analysis and failure prediction of construction equipment with time series model. According to this paper, due to unexpected break down (i.e. 46% unexpected breakdown in each construction equipment) and repair of construction equipment during the operation cause the serious things such as extra cost and extension of project period. Therefore, study of the reliability is necessary for the construction equipment's to predict the forecasting failures. It has been analyzed that, real breakdown data from field which is obtained in case study to test and validate the results by using the software DTREG. Also this work shown that, time series model can be used to describe and model the selected data and forecast the future data of the series based on the past data by using ARIMA (Auto Regressive Integrated Moving Average). The failure of the construction equipment follows the time series model to investigate the forecasting failures of the construction equipment, to analyze reliability and availability characteristic such as MTBF, MTTF, MTTR and expected failures per period of interval of the construction equipment's. It has notice that best fit curve such as Weibull, exponential and lognormal distribution curves based on the obtained field data and valid results.

Sankha and Dev (2015) studied reliability modeling of side discharge loader for availability estimation and maintenance planning in underground coal mines. It has been analyzed that, analysis of the RAM of the side discharge loader in underground coal mine for 16 years. It has been done that, the failures of the repairable sub systems such as drive unit, transmission, hydraulic, traction, bucket and other miscellanies have been modeled on the basis of the renewal processes (homogenous and non-homogenous Poisson process). In NHPP, TBF is assumed to be an independent and distributed identification (IID), and the failure data is characterized for modeling by appropriate PDF. In a HPP, TBF is assumed to be exponentially distributed or with a constant failure rate. In addition, the reliability as well as maintainability analysis of mining machines was found based on the Markov process.

Mohammadi et al. (2015) carried out performance measurements of mining equipment. It has been carried out, the performance of mining equipment's by using the reliability, availability and maintainability in mining industries. This papers was mainly concentrated on the, various forms of the operation availability during mining process based the mine parameters such as, routine maintenance activities, shut down time, break down time, shift changing, lunch break and non-availability of operator are considered as idle time. Also it has been discussed that, performance characteristic of the overall equipment effectiveness (WEE), it seems to be contemporary and truly relevant to address the growing demand on the production and productivity. Overall equipment effectiveness (OEE) of mining equipment has been calculated by mathematical equitation's i.e., $OEE=0.3A\times0.5P\times0.2U$ and $A\times U\times PI$ (Where A is operational availability, P is Performance, U is Utilization and PI is Production Index).

Dubey et al. (2015) studied reliability study of 42 cu. m shovel and 240 Te dumper equipment systems with special reference to Gevra OCP, SECL, Bilaspur. As per the authors, the frame work for integrated mining system is developed for reliability improvement to address issues of availability and maintainability of the LHD machine unavailability is outlined. It has been studied that the failure behavior of the component is influenced by the operating context, specifically the characteristic of the mineral and to identify factor that might be driving that behavior. Also, it has done RAM analysis of LDH to improve the performance of the equipment, productivity, and to decrease the failure rate by using patero analysis. Here the calculated reliability of this machine based on the probability, overall probability of these 42 cu.m shovel and 240 Te dumpers are 0.052 and 0.433 respectively and reliability is 94.73% and 56.63% respectively.

Aveek et al. (2015) studied investigated a methodology for reliability, availability and maintainability of load haul dumper in an underground coal mine through industrial automation – a new trend setter. As per the authors, the frame work for integrated mining system is developed for reliability improvement to address issues of availability and maintainability of the LHD machine unavailability is outlined. It has been studied that the failure behavior of the component is influenced by the operating context, specifically the characteristic of the mineral and to identify factor that might be driving that behavior. Today this goal has been achieved with an automation system that offers productivity that is similar to or better in composition with manually operated vehicles and driverless vehicles (Remote controlled). The RAM analysis of LDH were done to improve the performance of the equipment, productivity, and to decrease the failure rate by using Patero analysis.

Hasan et al. (2015) studied investigated reliability block diagrams based analysis: a survey. It has been studied that, RBD's are allowed using the model the failure relationships of complex systems and their sub systems and are extensively used for system RAM analyses of many mechanical systems. Traditionally, RBD has analyzed by using paper and pencil proofs or computer simulations. Recently, formal techniques, including petri nets and higher-order-logic theorem such as $R(t) = Pr(X > t) = 1- Pr(X \leq t) = 1- FX (t)$, have been used for their analysis as well. In this regard, it has been proposed to build upon the foundations of to formalize other commonly used RBDs, such as parallel, series-parallel and parallel-series.

Sankha et al. (2015) studied reliability and availability improvement of side discharge loaders by using importance measure in underground coal mines. It has been carried out, the reliability analysis of the side discharge loader in underground coal mine to improve the performance characteristics and failure rate of the side discharge loader. Also, it has been studied that, the side discharge loader consisting of the six major sub systems such as power generating unit, transmission, hydraulic, track chain, a bucket, electric and other connecting series to calculate the time to failure, time to repair and availability of the each sub system easily. It has also studied that, Trend test and series correlation test also performed graphically by plotting the TBF or TTR i^{th} with TBF or TTR $(i-1)^{th}$. It has been analyzed that, reliability, availability and maintenance by using the Markove's process and also it has been performed that, failure frequency of the each sub system of the side discharge loader can be determined by Pareto analysis.

Ajabhai et al. (2016) studied shovel performance analysis and geological aspect of the limestone mine. It has been studied that, relation between the performance analysis and the geological aspects of the limestone mine. Here most important thing is, availability, MTTF, MTTR and utilization of shovel has calculated to achieve cost effectiveness and also calculated useful life of the shovel i.e., useful life of the shovel has 25 thousand years but in limestone mine (J. K. Lakshmi limestone mine Rajasthan) it has been worked 40 thousand hours from last 20 years. Based on the geological factors such as toughness, harness of the rock and specific gravity has been calculated availability of shovels. In this paper reliability parameters such as availability, MTBF and MTTR has been calculated on working hours, breakdown hours and maintenance hours for 9 shovel during the period of 2 years. I has concluded that, due to high MTTR, some shovels are not working properly i.e., availability of the shovel in period of 2 years is 82% and 77% respectively.

Dindarloo et al. (2016) studied measuring the effectiveness of mining shovel. It has been studied that, comparison of stochastic shovel effectiveness (SSE) based method overall equipment effectiveness (OEE) between the electrical and hydraulic shovel which are dominating the loading equipment's in the surface mines and in manufacturing industries. These OEE has calculated by using the multiplying mechanical availability, utilization and production quality i.e., OEE=A×P×Q where A is availability, P is Performance and Q is Quality rate. Also in this case it has studied that Bucyrus BI495HR electrical rope shovel and RH400 hydraulic O&K shovel for one year to validate the model and two shovels were operated at same time. In this case study it has analyzed that stochastic characteristics of TTRs, Stochastic characteristics of effective utilizations and stochastic characteristics of bucket rates and calculation of the SSEs.

Kumar et al. (2018) studied maintenance helps to extend equipment life by improving its condition and avoiding catastrophic failures. Appropriate model or mechanism is, thus, needed to quantify system availability vis-a-vis a given maintenance strategy, which will assist in decision-making for optimal utilization of maintenance resources. This paper deals with Semi-Markov process (SMP) modeling for steady state availability analysis of mechanical systems that follow condition-based maintenance (CBM) and evaluation of optimal condition monitoring interval. The developed SMP model is solved using two-stage analytical approach for steady-state availability analysis of the system. Also, CBM interval is decided for maximizing system availability using genetic algorithm approach. The main contribution of the paper is in the form of a predictive tool for system availability that will help in deciding the optimum CBM policy. The proposed methodology is demonstrated for a centrifugal pump.

Palei et al. (2020) carried out machine manufacturers' recommendations on maintenance strategies of capital-intensive draglines are not always based on real data and therefore lead to losses from downtime. This research work proposes a preventive maintenance strategy for a dragline deployed in an opencast coal mine based on reliability-centered maintenance and failure-mode-effects analysis using real operational data. Maintenance focuses on reliability, replacing parts of the main driveline failure components while two specific conditions are met: (i) The components must be replaced when the first failure means (failure) in the group and (ii) Time to replace. The estimated weight factors identified twenty-six major failure components for preventive maintenance strategies and the nine component grouping. In the group, the losses that are expected to occur by replacing some components before their failure, and the gains by reducing the total waiting time for maintenance, are explained through cost-benefit analysis.

Wang and Fang (2020) carried out a new reliability analysis method was developed based on the adaptive high-dimensional model representation (HDMR) and applied to geotechnical engineering problems. For practical problems that require finite element analysis or other numerical methods to evaluate system responses, such as stress and deformations, an efficient and accurate Meta modeling technique is necessary because it is inefficient or easy to accept. In the research work, based on the HDMR framework and additional radical base functions (ARBFs) Meta modeling approach were developed and studied. In this adaptive ARBF-HDMR technique, the first simple and inexpensive first-order ARBF-HDMR meta model was first constructed to explicitly express a performance function, and an alternate first-order reliability method (FORM) was applied to locate the design point and compute the reliability index.

2.11 Summary of Literature Review and Gap

From the literature review, it was observed that most of the researchers have confined their efforts to develop theoretical models and analyzed having very little practical significance. Very few researchers have tried to develop mathematical models for shovel and dumper separately/individually (not in combination) for a specific operating surface mine. In order to fulfill these deficiencies, efforts were made in this thesis to develop real performance models for shovel-dumper sytem in three different surface mines (operating mines) and thereby to analyze and optimize the performance of shovel and dumper by using RBD and Markov models based on Weibull distributions.

Previous researchers have considered few subsystems (4 to 5 subsystems) for shovel and dumper and also other mining equipments. Where as in this study, 10 subsytems were considered based on failure data.

CHAPTER 3

ORIGIN, OBJECTIVES, PURPOSE AND SCOPE OF THE RESEARCH WORK

3.1 Origin of Research Work

Each year around the world billions of dollars are spent on mining equipment maintenance. Since the mining sector revolution, maintenance of mining equipment's has been a real challenging issue. Over the years remarkable progress has been made in maintaining engineering equipment in the field mining engineering, but it has remained a challenge due to factors such as more and frequent breakdowns, complexity, size, competition, cost, and safety. Also, the increase in mechanization and automation within the mines has further complicated the issue of maintenance. In this regard, the study of reliability, availability and maintainability of a system has assumed great significance due to a competitive environment and overall operating and production costs. The requirements for the reliability, availability and maintainability study of such systems are very much desirable. There is an expectation that machinery and technology are supposed to be available at all times, ready for use and have a high performance. It is, therefore, very important to increase the reliability or availability of a system in the mining industry. The machinery is increasing in complexity and size, which adds to the list of challenges in the mining industry.

The economy is very important and crucial in today's mining industry. With the correct use, high reliability can be achieved, resulting in lower maintenance costs and, therefore, higher profits. The focus of this improvement is to take a reliability and availability approach to increase the viability of the production line. Using this method can save resources in many ways, such as transportation, repair, without the need for more production etc. The surface mine production equipment, such as shovel and dumper with their many subsystems and components. The failure of each subsystems and components influences the availability and reliability of the overall production line. Therefore, each subsystem and component must be analyzed to determine how this component affects the availability and reliability of the system as a whole. To increase the reliability of any machine, it is necessary to study it to determine the necessary improvements or modifications that must be executed. By achieving these objectives it is possible to improve the production of surface mine by increasing the availability and reliability of machinery and in particular shovel and dumper.

3.2 Objectives

1. To carry out reliability, availability and maintainability analysis of shovel and dumper in three different surface mines i.e., coal, iron ore and limestone mine using Isograph Reliability Workbench 13.0.
2. To develop the mathematical models for reliability block diagram (RBD) for shovel and dumper and validating with of field data.
3. To develop a model for reliability improvement of each subsystem of shovel and dumper in surface mines using Markov modelling and to compare the reliability of shovel and dumper in coal, iron ore and limestone mine.

3.3 Purpose of the Research Study

The purpose of this research study is to describe the method of reliability, availability and maintainability analysis of a repairable system and subsystems of shovel and dumper in three different mines. These explore the method to identify the criticality and sensitivities of the subsystems using RBD and obtained mathematical models that are useful for similar mines. Also, it will suggest the best configuration of shovel and dumpers to achieve more reliability. This analysis will also examine that way of methods for improving the system reliability and availability of subsystems of shovel and dumper using Markov analysis. This research study also intends to look into the overall system reliability, availability and maintainability of the same shovel and dumper. So that required action can be taken to improve the situation.

3.4 Scope of Research Work

The scope of this work is the reliability analysis of the shovel and dumper in Indian surface mines by considering both the system and their subsystems using statistical modelling software i.e., Isograph Reliability Workbench and characterization of each system by RBD and Markov modelling. The research work covers collection of data related to failures of systems and subsystems of shovel-dumper system in Indian surface mines. The reliability-based models such as reliability block diagram and Markov model was considered for finding the most critical subsystem and also to improve the reliability of shovel and dumper. Also, reliability-based preventive maintenance was calculated using the Reliability Isograph Workbench under Weibull distribution. In this study, application of reliability analysis using RBD and Markov model and mathematical model (developed based on failure rate) can be done for shovel and dumper in other surface mine of similar condition.

CHAPTER 4

RESEARCH METHODOLOGY

The main objective of this study was to analyze the RAM of shovels and dumpers in three different surfaces mines (i.e., surface coal mine, surface iron ore mine and surface limestone mine) using the Isograph Reliability Workbench. The reliability must be analyzed using quantitative methods to provide some practical impact. The flow chart of the research work is shown in Figure 4.1. The research work involves the following steps for RAM analysis.

4.1 Identification of System and Data Collection

For the RAM analysis, the sizes of the time between failure (TBF) and time to repair (TTR) data were determined. The data are quantitative and are based on raw data/failure data collected over a period of one year. The data collected comes from daily wait time reports and maintenance log book. The failure data used in the current study are secondary data. It means that someone other than the analyst collects it for some general purpose. In this case, the general purpose of data collection is to obtain information on production and maintenance. After collection, processing (sorting and sorting), the failure data is applied. After processing, the data is in a format that can be used for statistical analysis. This analysis deals with either repairable or non-repairable system, and the collected data is the failure and repair time of the subsystem that compiles the entire system.

4.2 Data Evaluation

Describes the approach needed to evaluate the collected data to select the probability of fit and statistical analysis techniques. The main assumption of the data is that the data collected is independent and identically distributed (IID). This assumption needs verification by appropriate statistical tests, such as the trend and serial correlation test and explained below (Behera et al. 2011).

4.2.1 IID assumption

Assuming the data set is IID indicates that the probability distribution can be used to model subsystems. If the data set does not meet the IID requirements, the probability distribution is used to model and analyze for reliability of shovel and dumper (Kumar et al. 1989; Kumar et al. 2018). Assuming that, the data set is independent means that a failure does not depend on the previous data, indicating that the selected partition parameters do not change over time. Assuming the data set is identical, the different data points follow the same distribution. Non-uniform processes, such as the Poisson process, can be used to model instead of probability distribution in cases where IID requirements are not met (Kumar et al. 1989). Trend tests can verify independent assumptions analytically or graphically. In this study, IID assumptions will be graphically examined.

4.2.2 Trend test

In trend testing, a cumulative TBF or TTR is plotted against a cumulative failure number or repair number. If a line is drawn along a data point similar to the concave upwards or concave downwards trend of the data, the system is improving or deteriorating, respectively. However, if the lines drawn through the data points are approximately straight, then the data is unbiased, which means that the data set is identically distributed (Kumar et al. 1989).

4.2.3 Serial correlation test

In the serial correlation test, the $(i-1)^{th}$ TBF/TTR is plotted against the i^{th} TBF/TTR. If the data points are randomly scattered without a clear pattern, it implies a data set free from serial correlation, indicating that the data points in the data set are independent of each other (Kumar et al. 1989; Vayenas and Wu 2009).

4.2.4 Data analysis

This section describes the methods used for data analysis. The system is modeled based on the analysis of TBF and TTR data. The optimal probability distribution is determined by testing and the optimal parameters for the best fit distribution are estimated by the maximum likelihood estimation method.

4.2.5 Goodness-of-fit Test

The principle behind the goodness-of-fit tests is to see if the selected distribution matches the actual data set, or in other words, how the selected distribution represents the observed distribution. One of the most widely used tests in the RAM analysis is the Kolmogorov-Smirnov (K-S) test. The original K-S test is applicable for distributions with known parameters. In cases where the parameters are calculated based on self-defined data, a modified K-S test can be used. After an adequate distribution of the data determines the parameters of a specific distribution, it is necessary to estimate it. There are several methods available, such as the regression method, the maximum likelihood estimation (MLE), and the Bayesian estimation method. In the present study, the MLE method will be used (Rahimdel et al. 2013). The Isograph reliability workbench is used for quality testing and parameter estimation using the MLE method.

4.2.6 About Isograph Reliability Workbench

Reliability Workbench incorporating Fault Tree$^+$ is the world leading software (statistical tools) suite for reliability and safety analysis of systems. It is widely used in industries such as Aerospace, Defence, Railroads, Automotive, Oil and Gas, Chemical Process, Mining Industries and Nuclear Power. Reliability Workbench is an integrated environment for performing Reliability Prediction, Allocation and Growth, Maintainability Prediction, FMECA, Reliability Block Diagram Analysis, Fault Tree Analysis, Event Tree Analysis, Markov Analysis and Weibull Analysis. Each of the modules is a powerful application in its own right and can be used independently. More power is gained by the integration of the modules in the Reliability Workbench environment. They can dynamically share data for ease and consistency. Users only need to input data once but can use it multiple times with the new Enterprise functionality, Reliability Workbench projects can be stored centrally on a corporate network. The projects can be checked in and out by multiple users. Reliability Workbench handles version control and user permissions for the enterprise projects. Reliability Workbench has been in continuous development since 1990. It is a mature product with an impressive track record. Reliability Workbench is used in mission critical applications where its industrial strength is essential.

Key Features:

i) Fully integrated environment for performing reliability, safety and availability analysis.

ii) Enterprise facilities for large-scale collaboration and version control.

iii) Intuitive Reliability Prediction adhering to multiple industry standards

iv) Maintainability Prediction.

v) Failure Mode, Effects and Criticality Analysis including industry standard formatting.

vi) Reliability Block Diagram Analysis.

vii) Fault Tree Analysis.

viii) Event Tree and Markov Analysis.

ix) Weibull Analysis of historical failure data.

x) Reliability Allocation.

xi) Reliability Growth.

xii) Integrated parts libraries with data for electronic and mechanical parts.

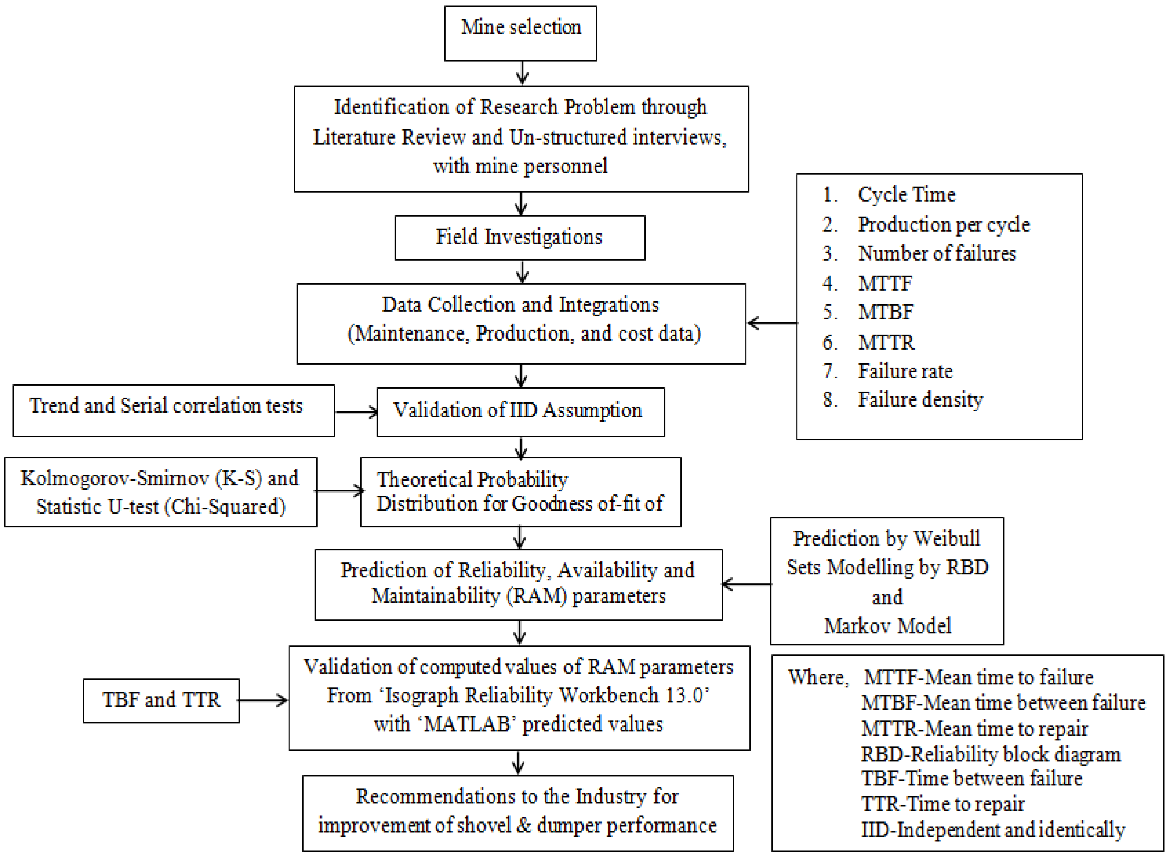


Figure 4.1 Flow chart of reliability prediction and analysis

CHAPTER 5

FIELD INVESTIGATIONS IN INDIAN SURFACE MINES

5.1 Surface coal mine

5.1.1 Study area

This case study was carried out at surface coal mine named as Opencast-I (OC-I) of M/s The SCCL, Kothagudem area, Telangana. This mine used a number of shovels and dumpers of different make i.e., Komatsu and BEML having different capacity. The capacities of the shovels are 6.5, 11 and 12 cubic meter and dumpers are 35, 65 and 100 tons. Also, in this study, the breakdown (TBF) and repair (TTR) of each shovel and dumper were collected for the one-year period of working hours (Table A.1, Annexure-A). These TBF and TTR of each shovel and dumper were collected for the 5400 operating hours over past one year and the details of mine operation are given in Table 5.1.

Table 5.1 Time length of the mine operation

Sl. No	Descriptions	Total time
1	Number of days/year	365 days
2	Nonscheduled time	65 days
3	Total scheduled days/year	365-65=300 days
4	Number of working days/month	25 days
5	Number of shifts/day	3
6	Number of hours/shift	8, hrs
7	Maintenance Hours & Idle hours/shift	2, hrs
8	Effective working hours/shift	6 hours
9	Effective working hours / day	6×3 = 18 hours
10	Effective working hours / year	300×18 =5400 hours

5.1.2 Match factor

In this surface mine, to improve the productivity of coal, large numbers of heavy equipment such as shovel and dumper were used. Because of significant investments involved, no mine can afford an inefficient work of its equipment and his subsequent increase in the idle time because of the significant investment. Therefore, in during the selection process of equipment’s, consideration must be given to the proper matching of equipment. By comparing shovel and dumper productivities, it can be seen whether they match or not. In this case study, two shovels (KS1 & KS2) i.e., 12 cubic meters which are made by Komatsu and eight dumpers (BD3, BD4, BD5, BD6, KD7, KD8, KD9 and KD10) i.e., 100 T each which is made by Komatsu and BEML were selected based on the match factor (i.e., 1:4). The calculation of best match factor for the shovel and dumper in coal mine is mentioned in Section B.1, Annexure-B. Based on the match factor, two shovels and eight dumpers having different make and same capacity were selected for the research work. The specification of the selected shovel and dumper are given in Table 5.2.

Table 5.2 Specifications of the shovel-dumper system

Sl. No.	Name of the Equipment	Make	Capacity	Equipment Code
1	Shovel	Komatsu	12 cubic meter	KS1, KS1
2	Dumper	BEML	100 T	BD3, BD4, BD5, BD6,
3	Dumper	Komatsu	100 T	KD7, KD8, KD9, KD10
BEML-Bharat Earth Movers Ltd, KS-Komastu Shovel, BD-BEML Dumper, KD-Komastu Dumper				

5.1.3 Breakdown data of shovel-dumper system

The breakdown data (i.e., TBF: Time between failure and TTR: Time to repair) of the above mentioned shovels and dumpers were collected for 5400 operating hours for one year. The detailed of breakdown hours and its causes of the shovel-dumper system in the surface coal mine were collected and given in Table A.1, Annexure-A. Also, details of failures with cause for each shovel and dumper were given in Section C.1, Annexure-C and Section C.2, Annexure-C respectively. Based on these failure data, each shovel and dumper is categorized into 10 subsystems and all are connected in series. The subsystems of shovel and dumper and their failure codes are given is Table 5.3.

Table 5.3 Subsystems of the shovel and dumper with failure code

Sl. No	Shovel subsystems	Failure code	Dumper subsystems	Failure Code
1	Arm Cylinder	SS1	Braking	DS1
2	Boom Cylinder	SS2	Differential	DS2
3	Bucket	SS3	Drive train	DS3
4	Cab and its attachments	SS4	Electrical	DS4
5	Electrical	SS5	Engine	DS5
6	Engine	SS6	Hydraulic suspension	DS6
7	Hydraulic	SS7	Steering	DS7
8	Power train	SS8	Structural	DS8
9	Structure	SS9	Tires and Rims	DS9
10	Undercarriage and frame	SS10	Transmission	DS10

5.1.4 Failure frequency

There are ten subsystems in each shovel (KS1 and KS2) and dumper (i.e., BD3, BD4, BD5, BD6, KD7, KD8, KD9 and KD10) and each subsystem having different failure frequency. Figure 5.1 shows the number of failures of the subsystem (maximum failure of subsystems only) of each shovel and dumper. The failure frequency (in %) of each subsystem of the shovel-dumper system were calculated and given in Table. 5.4. From Table 5.4 it is understood, that SS5 (Electrical subsystem) and SS7 (Hydraulic subsystem) failed 29.8% each in KS1 and SS7 (Hydraulic subsystem) failed 28.7% in KS2. Similarly, DS4 (Electrical subsystem) failed 23.2% in BD3, 23.9% in BD4, 40.9% in KD7, 29.1% in KD8, 36.1% in KD9 and 35.8% in KD10. Also, DS10 (Transmission subsystem) failed 36.6% in BD5 and DS5 (Engine) failed 42.2% in BD6. It is observed that the number of failures KS1 (i.e., $N_{(KS1)}$=181) and KD8 ($N_{(BD8)}$=151) are more compared to other shovel and dumpers. The percentage of the failures in each shovel and dumper are shown in Figure 5.1.

Once the information related to failure and repair time is collected and analyzed, the MTBF, failure rate MTTR and repair rate are determined. MTBF is determined by dividing the total operating time for the period to analyze by the number of failures in that period. MTBF can be defined for units that are specific subsystems of shovel and dumper. The failure rate is the reciprocal of MTBF and repair rate is the reciprocal of MTTR.

The MTTR is the total time to repair a unit, subsystem of shovel and dumper during a specific time period divided by the number of repairs. The repair rate of each subsystem was calculated. The repair rate is the number of repairs per TTR. In other words, it is the reciprocal of MTTR. The calculated MTBF, failure rate, MTTR and repair rate of each subsystem was calculated and given in Table. 5.5.

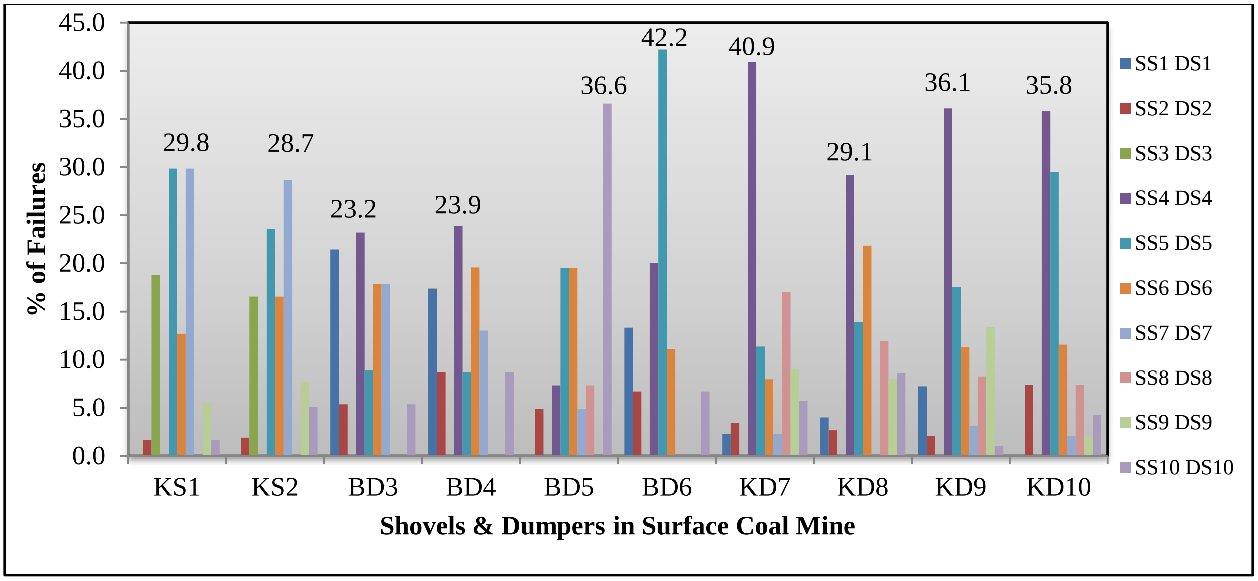


Figure 5.1 Percentage of failures in shovel and dumper in surface coal mines

Table 5.4 Summary of No. failures (in %) of shovel-dumper system in surface coal mine

SS's →		SS1	SS2	SS3	SS4	SS5	SS6	SS7	SS8	SS9	SS10	N
KS1	**n_1**	$n_{1(SS1)}=0$	$n_{1(SS2)}=3$	$n_{1(SS3)}=34$	$n_{1(SS4)}=0$	$n_{1(SS5)}=54$	$n_{1\ (SS6)}=23$	$n_{1\ (SS7)}=54$	$n_{1\ (SS8)}=0$	$n_{1(SS9)}=10$	$n_{1(SS10)}=3$	$N_{(KS1)}=181$
	%	0	1.7	18.8	0	29.8	12.7	29.8	0	5.5	1.7	100
KS2	**n_2**	$n_{2(SS1)}=0$	$n_{2\ (SS2)}=3$	$n_{2\ (SS3)}=26$	$n_{2\ (SS4)}=0$	$n_{2\ (S5)}=37$	$n_{2\ (SS6)}=26$	$n_{2\ (SS7)}=45$	$n_{2\ (SS8)}=0$	$n_{2\ (SS9)}=12$	$n_{2\ (SS10)}=8$	$N_{(KS2)}=157$
	%	0	1.9	16.6	0	23.6	16.6	28.7	0	7.6	5.1	100
SS's →		**DS1**	**DS2**	**DS3**	**DS4**	**DS5**	**DS6**	**DS7**	**DS8**	**DS9**	**DS10**	**N**
BD3	**n_3**	$n_{3(DS1)}=12$	$n_{3\ (DS2)}=3$	$n_{3\ (DS3)}=0$	$n_{3\ (DS4)}=13$	$n_{3\ (DS5)}=5$	$n_{3\ (DS6)}=10$	$n_{3\ (DS7)}=10$	$n_{3\ (DS8)}=0$	$n_{3\ (DS9)}=0$	$n_{3\ (DS10)}=3$	$N_{(BD3)}=56$
	%	21.4	5.4	0	23.2	8.9	17.9	17.9	0	0	5.4	100
BD4	**n_4**	$n_{4(DS1)}=8$	$n_{4\ (DS2)}=4$	$n_{4\ (DS3)}=0$	$n_{4(DS4)}=11$	$n_{4\ (DS5)}=4$	$n_{4\ (DS6)}=9$	$n_{4\ (DS7)}=6$	$n_{4\ (DS8)}=0$	$n_{4\ (DS9)}=0$	$n_{4\ (DS10)}=4$	$N_{(BD4)}=46$
	%	17.4	8.7	0	23.9	8.7	19.6	13	0	0	8.7	100
BD5	**n_5**	$n_{5(DS1)}=0$	$n_{5\ (DS2)}=2$	$n_{5\ (DS3)}=0$	$n_{5\ (DS4)}=3$	$n_{5\ (DS5)}=8$	$n_{5\ (DS6)}=8$	$n_{5\ (DS7)}=2$	$n_{5\ (DS8)}=3$	$n_{5\ (DS9)}=0$	$n_{5\ (DS10)}=15$	$N_{(BD5)}=41$
	%	0	4.9	0	7.3	19.5	19.5	4.9	7.3	0	36.6	100
BD6	**n_6**	$n_{6(DS1)}=6$	$n_{6\ (DS2)}=3$	$n_{6\ (DS3)}=0$	$n_{6\ (DS4)}=9$	$n_{6\ (DS5)}=19$	$n_{6\ (DS6)}=5$	$n_{6\ (DS7)}=0$	$n_{6\ (DS8)}=0$	$n_{6\ (DS9)}=0$	$n_{6\ (DS10)}=3$	$N_{(BD6)}=45$
	%	13.3	6.7	0	20	42.2	11.1	0	0	0	6.7	100
KD7	**n_7**	$n_{7(DS1)}=2$	$n_{7\ (D21)}=3$	$n_{7\ (DS3)}=0$	$n_{7\ (DS4)}=36$	$n_{7\ (DS5)}=10$	$n_{7\ (DS6)}=7$	$n_{7\ (DS7)}=2$	$n_{7\ (DS8)}=15$	$n_{7\ (DS9)}=8$	$n_{7\ (DS10)}=5$	$N_{(BD7)}=88$
	%	2.3	3.4	0	40.9	11.4	8	2.3	17	9.1	5.7	100
KD8	**n_8**	$n_{8(DS1)}=6$	$n_{8\ (DS2)}=4$	$n_{8\ (DS3)}=0$	$n_{8\ (DS4)}=44$	$n_{8\ (DS5)}=21$	$n_{8\ (DS6)}=33$	$n_{8\ (DS7)}=0$	$n_{8\ (DS8)}=18$	$n_{8\ (DS9)}=12$	$n_{8\ (DS10)}=13$	$N_{(BD8)}=151$
	%	4	2.6	0	29.1	13.9	21.9	0	11.9	7.9	8.6	100
KD9	**n_9**	$n_{9(DS1)}=7$	$n_{9\ (DS2)}=2$	$n_{9(DS3)}=0$	$n_{9(DS4)}=35$	$n_{9(DS5)}=17$	$n_{9(DS6)}=11$	$n_{9(DS7)}=3$	$n_{9(DS8)}=8$	$n_{9(DS9)}=13$	$n_{9(DS10)}=1$	$N_{(BD9)}=97$
	%	7.2	2.1	0	36.1	17.5	11.3	3.1	8.2	13.4	1	100
KD10	**n_{10}**	$n_{10(DS1)}=0$	$n_{10(DS2)}=7$	$n_{10(DS3)}=0$	$n_{10(DS4)}=34$	$n_{10(DS5)}=28$	$n_{10\ (DS6)}=11$	$n_{10\ (DS7)}=2$	$n_{10\ (DS8)}=7$	$n_{10\ (DS9)}=2$	$n_{10\ (DS10)}=4$	$N_{(BD10)}=95$
	%	0	7.4	0	35.8	29.5	11.6	2.1	7.4	2.1	4.2	100

Where, KS-Komastu Shovel, BD-BEML Dumper, KD-Komstu Shovel, SS's-Subsystem's, n_1, n_2, n_3.....are Number of failures of each subsystem, N-Total Number of failures in each shovel and dumper, $N=n_1+ n_{2+} n_{3+} n_{4+} n_{5+} n_{6+} n_7 +n_{8+} n_{9+} n_{10}$

Table 5.5 Failure and repair data of various subsystems of the shovel-dumper system in the surface coal mine

Systems↓	**SS's →**		**SS1**	**SS2**	**SS3**	**SS4**	**SS5**	**SS6**	**SS7**	**SS8**	**SS9**	**SS10**
KS1	**N**	$N_{(KS1)}=181$	$n_{1(SS1)}=0$	$n_{1(SS2)}=3$	$n_{1(SS3)}=34$	$n_{1(SS4)}=0$	$n_{1(SS5)}=54$	$n_{1(SS6)}=23$	$n_{1(SS7)}=54$	$n_{1(SS8)}=0$	$n_{1(SS9)}=10$	$n_{1(SS10)}=3$
	MTBF	43.834	0	1581.25	193.469	0	111.897	281.238	164.941	0	601.052	1606.1981
	λ	0.023	0	0.0006	0.005	0	0.0089	0.0036	0.0061	0	0.0017	0.00059
	MTTR	4.693	0	24	5.571	0	3.186	3.883	5.264	0	2.296	592.3533
	μ	0.213	0	0.042	0.179	0	0.314	0.258	0.190	0	0.436	0.0017
KS2	**N**	$N_{(KS2)}=157$	$n_{2(SS1)}=0$	$n_{2(SS1)}=3$	$n_{2(SS1)}=26$	$n_{2(SS1)}=0$	$n_{2(SS1)}=37$	$n_{2(SS1)}=26$	$n_{2(SS1)}=45$	$n_{2(SS1)}=0$	$n_{2(SS1)}=12$	$n_{2(SS1)}=8$
	MTBF	49.567	0	1050.914	333.277	0	196.266	271.397	152.419	0	511.901	573.680
	λ	0.020	0	0.001	0.003	0	0.0051	0.0037	0.0066	0	0.002	0.0017
	MTTR	7.487	0	1.580	6.934	0	3.939	11.022	10.454	0	1.493	8.568
	μ	0.134	0	0.633	0.144	0	0.254	0.091	0.096	0	0.670	0.117
Systems↓	**SS's →**		**DS1**	**DS2**	**DS3**	**DS4**	**DS5**	**DS6**	**DS7**	**DS8**	**DS9**	**DS10**
BD3	**N**	$N_{(BD3)}=56$	$n_{3(DS1)}=12$	$n_{3(DS2)}=3$	$n_{3(DS3)}=0$	$n_{3(DS4)}=13$	$n_{3(DS5)}=5$	$n_{3(DS6)}=10$	$n_{3(DS7)}=10$	$n_{3(DS8)}=0$	$n_{3(DS9)}=0$	$n_{3(DS10)}=3$
	MTBF	110.120	636.309	1611.201	0	538.745	482.856	351.262	881.594	0	0	1467.518
	λ	0.009	0.002	0.001	0	0.002	0.002	0.003	0.001	0	0	0.001
	MTTR	34.096	15.330	6.853	0	7.162	174.912	53.407	16.919	0	0	11.310
	μ	0.029	0.065	0.146	0	0.140	0.006	0.019	0.059	0	0	0.088
BD4	**N**	$N_{(BD4)}=46$	$n_{4(DS1)}=8$	$n_{4(DS2)}=4$	$n_{4(DS3)}=0$	$n_{4(DS4)}=11$	$n_{4(DS5)}=4$	$n_{4(DS6)}=9$	$n_{4(DS7)}=6$	$n_{4(DS8)}=0$	$n_{4(DS9)}=0$	$n_{4(DS10)}=4$
	MTBF	126.834	684.657	527.671	0	529.164	943.872	577.125	554.265	0	0	921.6857
	λ	0.0079	0.0015	0.0019	0	0.0019	0.0011	0.0017	0.0018	0	0	0.0011
	MTTR	32.612	8.686	6.300	0	24.353	6.578	55.189	96.562	0	0	8.7975
	μ	0.031	0.115	0.159	0	0.041	0.152	0.018	0.010	0	0	0.1137
BD5	**N**	$N_{(BD5)}=41$	$n_{5(DS1)}=0$	$n_{5(DS2)}=2$	$n_{5(DS3)}=0$	$n_{5(DS4)}=3$	$n_{5(DS5)}=8$	$n_{5(DS6)}=8$	$n_{5(DS7)}=2$	$n_{5(DS8)}=3$	$n_{5(DS9)}=0$	$n_{5(DS10)}=15$
	MTBF	127.6303	0	531.606	0	1786.639	613.200	1135.956	1907.988	1661.775	0	274.237
	λ	0.0078	0	0.002	0	0.0006	0.0016	0.0009	0.0005	0.0006	0	0.004
	MTTR	38.0602	0	15.695	0	16.537	44.311	22.506	2.575	4.467	0	61.759
	μ	0.0263	0	0.064	0	0.060	0.023	0.044	0.388	0.224	0	0.016

BD6	**N**	$N_{(BD6)}$=45	$n_{6(DS1)}$=6	$n_{6(DS2)}$=3	$n_{6(DS3)}$=0	$n_{6(DS4)}$=9	$n_{6(DS5)}$=19	$n_{6(DS6)}$=5	$n_{6(DS7)}$=0	$n_{6(DS8)}$=0	$n_{6(DS9)}$=0	$n_{6(DS10)}$=3
	MTBF	139.896	494.574	1041.135	0	738.209	184.762	739.457	0	0	0	1206.443
	λ	0.0071	0.0020	0.0010	0	0.0014	0.0054	0.0014	0	0	0	0.0008
	MTTR	18.552	38.060	70.560	0	10.418	11.482	17.328	0	0	0	94.747
	μ	0.054	0.026	0.014	0	0.096	0.087	0.058	0	0	0	0.011
KD7	**N**	$N_{(KD7)}$=88	$n_{7(DS1)}$=2	$n_{7(D21)}$=3	$n_{7(DS3)}$=0	$n_{7(DS4)}$=36	$n_{7(DS5)}$=10	$n_{7(DS6)}$=7	$n_{7(DS7)}$=2	$n_{7(DS8)}$=15	$n_{7(DS9)}$=8	$n_{7(DS10)}$=5
	MTBF	67.365	889.344	717.250	0	180.067	548.090	656.016	1372.413	341.509	882.431	733.360
	λ	0.015	0.0011	0.0014	0	0.0056	0.0018	0.0015	0.0007	0.0029	0.0011	0.0014
	MTTR	21.135	163.210	26.137	0	10.029	58.595	28.789	8.675	5.533	12.256	21.624
	μ	0.047	0.006	0.038	0	0.100	0.017	0.035	0.115	0.181	0.082	0.046
KD8	**N**	$N_{(KD8)}$=141	$n_{8(DS1)}$=6	$n_{8(DS2)}$=4	$n_{8(DS3)}$=0	$n_{8(DS4)}$=44	$n_{8(DS5)}$=21	$n_{8(DS6)}$=33	$n_{8(DS7)}$=0	$n_{8(DS8)}$=18	$n_{8(DS9)}$=12	$n_{8(DS10)}$=3
	MTBF	53.056	586.643	773.315	0	142.305	326.375	123.713	0	252.469	348.004	223.018
	λ	0.019	0.0017	0.0013	0	0.0070	0.0031	0.0081	0	0.0040	0.0029	0.0045
	MTTR	7.331	12.945	4.535	0	6.096	8.433	9.042	0	3.874	5.910	17.863
	μ	0.136	0.077	0.221	0	0.164	0.119	0.111	0	0.258	0.169	0.056
KD9	**N**	$N_{(KD9)}$=97	$n_{9(DS1)}$=7	$n_{9(DS2)}$=2	$n_{9(DS3)}$=0	$n_{9(DS4)}$=35	$n_{9(DS5)}$=17	$n_{9(DS6)}$=11	$n_{9(DS7)}$=3	$n_{9(DS8)}$=8	$n_{9(DS9)}$=13	$n_{9(DS10)}$=1
	MTBF	58.673	869.788	1845.375	0	126.799	459.852	698.582	1143.540	323.270	401.278	2553
	λ	0.017	0.0011	0.0005	0	0.0079	0.0022	0.0014	0.0009	0.0031	0.0025	0.0004
	MTTR	12.765	11.901	5.500	0	5.462	34.927	13.868	3.927	10.064	7.030	12.850
	μ	0.078	0.084	0.182	0	0.183	0.029	0.072	0.255	0.099	0.142	0.078
KD10	**N**	$N_{(KD10)}$=95	$n_{10(DS1)}$=0	$n_{10(DS2)}$=7	$n_{10(DS3)}$=0	$n_{10(DS4)}$=34	$n_{10(DS5)}$=28	$n_{10(DS6)}$=11	$n_{10(DS7)}$=2	$n_{10(DS8)}$=7	$n_{10(DS9)}$=2	$n_{10(DS10)}$=4
	MTBF	62.516	0	957.662	0	233.894	292.739	392.518	595.042	1123.931	923.375	716.462
	λ	0.016	0	0.001	0	0.0001	0.0034	0.0025	0.0017	0.0009	0.0011	0.0014
	MTTR	18.706	0	103.394	0	7.899	15.409	21.958	8.420	6.286	0.875	12.285
	μ	0.053	0	0.01	0	0.127	0.065	0.046	0.119	0.159	1.143	0.081

5.2 Surface Iron Ore Mine

5.2.1 Study area

This case study was carried out at M/s Subbarayanahalli iron ore mines and M/s The Mysore Minerals Ltd., Sandur (taken leases by JSW Steel Ltd, Toranagallu in the Bellary-Hospet area of Karnataka). This mine used a number of shovels and dumpers of different make i.e., Komatsu, BEML, L&T and Hino having different capacity. The capacities of the shovels are 2, 6.5, 11 and 12 cubic meter and dumpers are 35, 65 and 100 tons. In this study also, the breakdown (TBF) and repair (TTR) hours of each shovel and dumper were collected for the one-year period of working hours (3900 operated hours) over past one year (Table A.2, Annexure-A). The details of time length mine operation are given in Table 5.6.

Table 5.6 Time length of the mine operation

Sl. No	**Descriptions**	**Total time**
1	Number of days/year	365 days
2	Nonscheduled time	65 days
3	Total scheduled days/year	365-65=300 days
4	Number of working days/month	25 days
5	Number of shifts/day	2
6	Number of hours/shift	8 hrs
7	Maintenance Hours & Idle hours/shift	2 hrs
8	Effective working hours/shift	6.5 hours
9	Effective working hours / day	6.5×2 = 13 hours
10	Effective working hours / year	300×13 =3900 hours

5.2.2 Match factor

In this mine also, in order to improve productivity of iron ore, large numbers of heavy equipment such as shovel and dumper were used. Due to the huge investments involved, no mine can afford inefficient use of equipment or increased idle time of equipment. Therefore, in during the selection process of equipment, consideration must be given to the proper matching of equipment. By comparing shovel and dumper productivities, it can be seen whether they match or not. In this study, two shovels (KS11 and KS12) i.e., 3.4 to 4.3 cubic meters which is made by Komatsu and six dumpers (BD13, BD14, BD15, KD16, KD17 & KD18) i.e., 35 to 60 T each which is made by Komatsu and BEML both were selected based on the match factor (i.e., 1:3). The calculated of best match factor for the shovel and dumper given in Section B.2, Annexure-B. The based on the match factor, two shovels and six dumpers having different make and capacity were selected for the research work. The specification of the considered shovel and dumper are tabulated in Table 5.7.

Table 5.7 Specifications of the shovel-dumper system

Sl. No.	Name of the Equipment	Make	Capacity	Equipment Code
1	Shovel	Komatsu	4.3 cubic meter	KS11, KS12
2	Dumper	BEML	40 T	BD13, BD14, BD14,
3	Dumper	Komatsu	40 T	KD516, KD17, KD18

5.2.3 Breakdown data of shovel-dumper system

The break down data (i.e., TBF: Time between failure and TTR: Time to repair) of above mentioned shovels and dumpers were collected for 3900 operated hours for one year. The detail of breakdown hours and its causes of the shovel-dumper system in the surface iron ore mine were collected and given in Table A.1, Annexure-A. Also, details of failures with cause for each shovel and dumper were given in Section C.1, Annexure-C and Section C.2, Annexure-C respectively. Based on these failure data, the each shovel and dumper is categorized into 10 subsystems and all are connected in series. The subsystems of shovel and dumper and their failure codes are given in Table 5.3.

5.2.4 Failure frequency

There are ten subsystems in each shovel (i.e., KS11 & KS12) and dumper (i.e., BD13, BD14, BD15, KD16, KD17 & KD18) and each subsystem having different failure frequency. Figure 5.2 shows that, clear view of the number of failures of subsystem (maximum failure of subsystems only) of each shovel and dumper. The failure frequency (in %) of each subsystems of shovel-dumper system were calculated and given in Table. 5.8. From Table 5.8 it is understood that, SS3 (Bucket) and SS6 (Engine) is failed 29% each in KS11 and SS6 (Engine) is failed 48.3% in KS12. Similarly, DS8 (Power train) is failed 34.1% in BD13, 31.2% in BD14, 34.2% in BD15, 20% in KD16 including DS5 (Electrical subsystem) and DS6 (Engine), 40.5% in KD17 and 29.3% in KD18. Also, SS6 (Engine) in KS12 having more failures compared to other subsystems of shovel and dumper in one year duration. Also, DS8 (Power train) has most commonly failed subsystem in dumpers. In case of shovels, SS6

(Engine) is more failures i.e., 48.3% in KS12. With respect to number of failures KS1 (i.e., $N_{(KS11)}$=31) in shovels and KD8 (i.e., $N_{(BD14)}$=125) in dumpers having more failures compared to other shovel and dumpers. Once information regarding failures and repair times is gathered and analyzed, MTBF, failure rate, MTTR and repair rate were determined and given in Table 5.9.

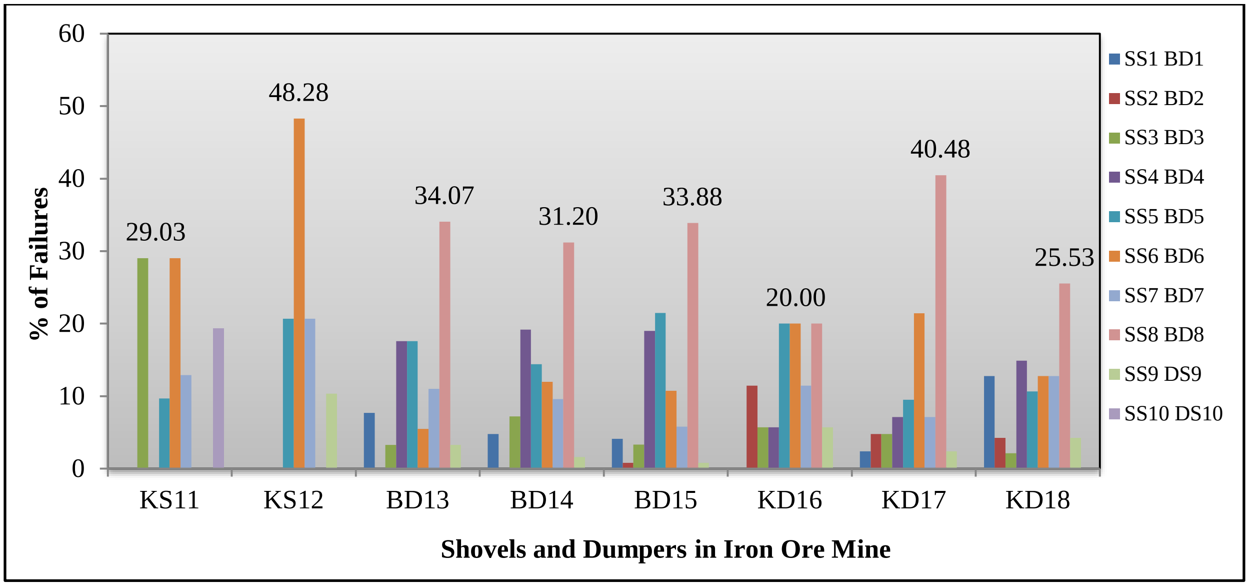


Figure 5.2 Percentage of failures in shovel and dumper in surface iron ore mine

Table 5.8 Summary of No. failures (in %) of shovel-dumper system in surface iron ore mine

SS's →		**SS1**	**SS2**	**SS3**	**SS4**	**SS5**	**SS6**	**SS7**	**SS8**	**SS9**	**SS10**	**N**
KS11	**n_1**	$n_{1(SS1)}=0$	$n_{1(SS2)}=0$	$n_{1(SS3)}=9$	$n_{1(SS4)}=0$	$n_{1(SS5)}=3$	$n_{1\,(SS6)}=9$	$n_{1\,(SS7)}=4$	$n_{1\,(SS8)}=0$	$n_{1(SS9)}=0$	$n_{1(SS10)}=6$	$N_{(KS11)}=31$
	%	0.0	0.0	29.0	0.0	9.7	29.0	12.9	0.0	0.0	19.4	100
KS12	**n_2**	$n_{2(SS1)}=0$	$n_{2\,(SS2)}=0$	$n_{2\,(SS3)}=0$	$n_{2\,(SS4)}=0$	$n_{2\,(SS5)}=0$	$n_{2\,(SS6)}=14$	$n_{2\,(SS7)}=6$	$n_{2\,(SS8)}=0$	$n_{2\,(SS9)}=3$	$n_{2\,(SS10)}=0$	$N_{(KS12)}=29$
	%	0.0	0.0	0.0	0.0	20.7	48.3	20.7	0.0	10.3	0.0	100
SS's →		**DS1**	**DS2**	**DS3**	**DS4**	**DS5**	**DS6**	**DS7**	**DS8**	**DS9**	**DS10**	**N**
BD13	**n_3**	$n_{3(DS1)}=7$	$n_{3\,(DS2)}=0$	$n_{3\,(DS3)}=3$	$n_{3\,(DS4)}=16$	$n_{3\,(DS5)}=16$	$n_{3\,(DS6)}=5$	$n_{3\,(DS7)}=10$	$n_{3\,(DS8)}=31$	$n_{3\,(DS9)}=3$	$n_{3\,(DS10)}=0$	$N_{(BD13)}=91$
	%	7.7	0.0	3.3	17.6	17.6	5.5	11.0	34.1	3.3	0.0	100
BD14	**n_4**	$n_{4(DS1)}=6$	$n_{4\,(DS2)}=0$	$n_{4\,(DS3)}=9$	$n_4 4_{(DS4)}=24$	$n_{4\,(DS5)}=18$	$n_{4\,(DS6)}=15$	$n_{4\,(DS7)}=12$	$n_{4\,(DS8)}=39$	$n_{4\,(DS9)}=2$	$n_{4\,(DS10)}=0$	$N_{(BD14)}=125$
	%	4.8	0	7.2	19.2	14.4	12	9.6	31.2	1.6	0	100
BD15	**n_5**	$n_{5(DS1)}=5$	$n_{5\,(DS2)}=1$	$n_{5\,(DS3)}=4$	$n_{5\,(DS4)}=23$	$n_{5\,(DS5)}=26$	$n_{5\,(DS6)}=13$	$n_{5\,(DS7)}=7$	$n_{5\,(DS8)}=41$	$n_{5\,(DS9)}=1$	$n_{5\,(DS10)}=0$	$N_{(BD15)}=120$
	%	4.2	0.8	3.3	19.2	21.7	10.8	5.8	34.2	0.0	0.0	100
KD16	**n_6**	$n_{6(DS1)}=0$	$n_{6\,(DS2)}=4$	$n_{6\,(DS3)}=2$	$n_{6\,(DS4)}=2$	$n_{6\,(DS5)}=7$	$n_{6\,(DS6)}=7$	$n_{6\,(DS7)}=4$	$n_{6\,(DS8)}=7$	$n_{6\,(DS9)}=2$	$n_{6\,(DS10)}=0$	$N_{(BD16)}=35$
	%	0.0	11.4	5.7	5.7	20.0	20.0	11.4	20.0	5.7	0.0	100
KD17	**n_7**	$n_{7(DS1)}=1$	$n_{7\,(D21)}=2$	$n_{7\,(DS3)}=2$	$n_{7\,(DS4)}=3$	$n_{7\,(DS5)}=4$	$n_{7\,(DS6)}=9$	$n_{7\,(DS7)}=3$	$n_{7\,(DS8)}=17$	$n_{7\,(DS9)}=1$	$n_{7\,(DS10)}=0$	$N_{(BD17)}=42$
	%	2.4	4.8	4.8	7.1	9.5	21.4	7.1	40.5	2.4	0.0	100
KD18	**n_8**	$n_{8(DS1)}=6$	$n_{8\,(DS2)}=2$	$n_{8\,(DS3)}=1$	$n_{8\,(DS4)}=7$	$n_{8\,(DS5)}=5$	$n_{8\,(DS6)}=6$	$n_{8\,(DS7)}=6$	$n_{8\,(DS8)}=12$	$n_{8\,(DS9)}=2$	$n_{8\,(DS10)}=0$	$N_{(BD18)}=41$
	%	14.6	4.9	2.4	17.1	12.2	14.6	0.0	29.3	4.9	0.0	100

Where, KS-Komastu Shovel, BD-BEML Dumper, KD-Komstu Shovel, SS's-Subsystem's, n_1, n_2, n_3.....are Number of failures of each subsystem, N-Total Number of failures in each shovel and dumper, $N=n_1+ n_{2+} n_{3+} n_{4+} n_{5+} n_{6+} n_7 +n_{8+} n_{9+} n_{10}$

Table 5.9 Failure and repair data of various subsystems of the dumper in the surface iron ore mine

Systems↓	SS's →		SS1	SS2	SS3	SS4	SS5	SS6	SS7	SS8	SS9	SS10
KS11	N	$N_{(KS11)}$=31	$n_{1(SS1)}$=0	$n_{1(SS2)}$=0	$n_{1(SS3)}$=9	$n_{1(SS4)}$=0	$n_{1(SS5)}$=3	$n_{1\,(SS6)}$=9	$n_{1\,(SS7)}$=4	$n_{1\,(SS8)}$=0	$n_{1(SS9)}$=0	$n_{1(SS10)}$=6
	MTBF	189.0026	0	0	644.4476	0	1510.583	400.2648	761.7335	0	0	987.7383
	λ	0.0053	0	0	0.001552	0	0.000662	0.002498	0.001313	0	0	0.001012
	MTTR	11.0732	0	0	6.202222	0	8.75	14.67778	5.0075	0	0	18.17833
	μ	0.0903	0	0	0.161232	0	0.114285	0.068130	0.1997	0	0	0.05501
KS12	N	$N_{(KS12)}$=29	$n_{2(SS1)}$=0	$n_{2\,(SS1)}$=0	$n_{2\,(SS1)}$=0	$n_{2\,(SS1)}$=0	$n_{2\,(SS1)}$=0	$n_{2\,(SS1)}$=14	$n_{2\,(SS1)}$=6	$n_{2\,(SS1)}$=0	$n_{2\,(SS1)}$=3	$n_{2\,(SS1)}$=0
	MTBF	59.3813	0	0	0	0	254.7392	72.20425	248.9738	0	301.0569	0
	λ	0.0168	0	0	0	0	0.003926	0.01385	0.004016	0	0.003322	0
	MTTR	3.6741	0	0	0	0	0.651667	1.653571	3.163333	0	3.933333	0
	μ	0.2722	0	0	0	0	1.534526	0.604751	0.316122	0	0.254237	0
Systems↓	**SS's →**		**DS1**	**DS2**	**DS3**	**DS4**	**DS5**	**DS6**	**DS7**	**DS8**	**DS9**	**DS10**
BD13	N	$N_{(BD13)}$=91	$n_{3(DS1)}$=7	$n_{3\,(DS2)}$=0	$n_{3\,(DS3)}$=3	$n_{3\,(DS4)}$=16	$n_{3\,(DS5)}$=16	$n_{3\,(DS6)}$=5	$n_{3\,(DS7)}$=10	$n_{3\,(DS8)}$=31	$n_{3\,(DS9)}$=3	$n_{3\,(DS10)}$=0
	MTBF	109.7461	778.3571	0	813.4444	501.6302	396.2552	253.6406	261.225	68.03226	1635.667	0
	λ	0.0091	0.001285	0	0.001229	0.001994	0.002524	0.003943	0.003828	0.014699	0.000611	0
	MTTR	32.5039	3.52381	0	1.055556	24.21354	76.40104	6.484375	4.025	39.14785	11	0
	μ	0.0308	0.283783	0	0.947368	0.041299	0.013088	0.154216	0.248447	0.025544	0.090909	0
BD14	N	$N_{(BD14)}$=125	$n_{4(DS1)}$=6	$n_{4\,(DS2)}$=0	$n_{4\,(DS3)}$=9	$n_4 4_{(DS4)}$=24	$n_{4\,(DS5)}$=18	$n_{4\,(DS6)}$=15	$n_{4\,(DS7)}$=12	$n_{4\,(DS8)}$=39	$n_{4\,(DS9)}$=2	$n_{4\,(DS10)}$=0
	MTBF	90.3619	1250.292	0	687.0833	319.5799	322.3991	524.7333	668.625	183.0876	1998	0
	λ	0.0111	0.0008	0	0.001455	0.003129	0.003102	0.001906	0.001496	0.005462	0.000501	0
	MTTR	14.3767	13.79167	0	11.86111	18.25347	17.40648	12.13333	10.25	12.83547	5.75	0
	μ	0.0696	0.07251	0	0.08431	0.054784	0.057450	0.082418	0.09756	0.07791	0.17391	0
BD15	N	$N_{(BD15)}$=120	$n_{5(DS1)}$=5	$n_{5\,(DS2)}$=1	$n_{5\,(DS3)}$=4	$n_{5\,(DS4)}$=23	$n_{5\,(DS5)}$=26	$n_{5\,(DS6)}$=13	$n_{5\,(DS7)}$=7	$n_{5\,(DS8)}$=41	$n_{5\,(DS9)}$=1	$n_{5\,(DS10)}$=0
	MTBF	110.0758	471.5333	23.16667	919.9375	234.5543	308.1635	638.8141	857.2857	208.5325	0	0
	λ	0.0091	0.002121	0.043165	0.001087	0.004263	0.003245	0.001565	0.001166	0.004795	0	0
	MTTR	15.7554	15.21667	23.16667	2.291667	8.163043	18.88782	18.95513	12.71429	9.418699	0	0
	μ	0.0635	0.0657	0.04317	0.436364	0.122503	0.052944	0.052756	0.078652	0.106172	0	0

KD16	**N**	$N_{(KD16)}$=35	$n_{6(DS1)}$=0	$n_{6\ (DS2)}$=4	$n_{6\ (DS3)}$=2	$n_{6\ (DS4)}$=2	$n_{6\ (DS5)}$=7	$n_{6\ (DS6)}$=7	$n_{6\ (DS7)}$=4	$n_{6\ (DS8)}$=7	$n_{6\ (DS9)}$=2	$n_{6\ (DS10)}$=0
	MTBF	324.4125	0	786.0833	2158.417	2335	876.9286	786.9762	1954.437	1096.238	2	0
	λ	0.0031	0	0.001272	0.000463	0.000428	0.00114	0.001271	0.000512	0.000912	0.5	0
	MTTR	77.9375	0	151.4167	15.75	2.875	43.30952	153.8095	16.3125	53.33333	12.25	0
	μ	0.0128		0.00660	0.06349	0.34783	0.02309	0.00650	0.061303	0.018750	0.08163	0
KD17	**N**	$N_{(KD17)}$=42	$n_{7(DS1)}$=1	$n_{7\ (D21)}$=2	$n_{7\ (DS3)}$=2	$n_{7\ (DS4)}$=3	$n_{7\ (DS5)}$=4	$n_{7\ (DS6)}$=9	$n_{7\ (DS7)}$=3	$n_{7\ (DS8)}$=17	$n_{7\ (DS9)}$=1	$n_{7\ (DS10)}$=0
	MTBF	336.0439	5.83	20	170.375	596.8333	206.5625	781.8426	13.33333	385.549	26	0
	λ	0.0030	0.171527	0.05	0.00586	0.001676	0.004841	0.001279	0.075	0.002594	0.038462	0
	MTTR	84.1404	7.17	412	218.666	18.72222	113.375	22.93519	281.1667	84.06863	24	0
	μ	0.0119	0.13947	0.00242	0.05341	0.00882	0.043601	0.043601	0.003556	0.011895	0.041666	0
KD18	**N**	$N_{(KD18)}$=41	$n_{8(DS1)}$=6	$n_{8\ (DS2)}$=2	$n_{8\ (DS3)}$=1	$n_{8\ (DS4)}$=7	$n_{8\ (DS5)}$=5	$n_{8\ (DS6)}$=6	$n_{8\ (DS7)}$=6	$n_{8\ (DS8)}$=12	$n_{8\ (DS9)}$=2	$n_{8\ (DS10)}$=0
	MTBF	265.6451	1045.056	1572.125	21	681.75	1467.25	879.2917	0	621.6042	2337	0
	λ	0.0038	0.000957	0.000636	0.047619	0.001467	0.000682	0.001137	0	0.001609	0.000428	0
	MTTR	36.5895	11.94444	26.375	16.08	17.67857	16.88333	56.20833	0	58.42361	18	0
	μ	0.0273	0.083720	0.037914	0.062189	0.056565	0.05923	0.01779	0	0.017116	0.055555	0

5.3 Limestone Line

5.3.1 Study area

This case study was carried out at The Thummalapenta Limestone Mine (Ultra Tech Cement Ltd mine) which is placed at Ramnagar, Tadipatri, Andhra Pradesh State. This mine used a number of shovels and dumpers of different makes i.e., Komatsu, BEML and Hitachi EX1200 having different capacity. The capacities of the shovels are 6.5 cubic meter and dumpers are 55 tons. In this study, the breakdown (TBF) and repair (TTR) hours of each shovel and dumper were collected for one-year period of working hours (Table A.3, Annexure-A). These TBF and TTR of each shovel and dumper were collected for the 4200 operating hours over past one year and the details about time length of the mine operation are shown in Table 5.10.

Table 5.10 Time length of the mine operation

Sl. No	**Descriptions**	**Total time**
1	Number of days/year	365 days
2	Nonscheduled time	65 days
3	Total scheduled days/year	365-65=300 days
4	Number of working days/month	25 days
5	Number of shifts/day	2
6	Number of hours/shift	8 hrs
7	Maintenance Hours & Idle hours/shift	1 hrs
8	Effective working hours/shift	7 hours
9	Effective working hours / day	7×2 = 14 hours
10	Effective working hours / year	300×13 =4200 hours

5.3.2 Match factor

Similarly, in this surface limestone surface mine, in order to improve productivity of limestone, large numbers of heavy equipment such as shovel and dumper were used. Due to the huge investments involved, No mine can afford an inefficient work of its equipment and his subsequent increase in the idle time because of the significant investment. Therefore, in during the selection process of equipment, consideration must be given to the proper matching of equipment. By comparing shovel and dumper productivities, it can be seen whether they match or not. In this study, two shovels (KS19 & KS20) i.e. 6.5 cubic meters which are made by Komatsu and six dumpers (BD21, BD22, BD23, KD24, KD25 & KD26) i.e., 55T each which is made by Komatsu and BEML both were selected based on the match factor (i.e., 1:3). The calculation of best match factor for the shovel and dumper which is used in limestone mine is shown in Section B.3, Annexure-B. The based on the match factor, two shovels and six dumpers having different makes and capacity were selected for the research work. The specification of the considered shovel and dumper are tabulated in Table 5.11.

Table 5.11 Specifications of the shovel-dumper system

Sl. No.	**Name of the Equipment**	**Make**	**Capacity**	**Equipment Code**
1	Shovel	Komatsu	6.5 cubic meter	KS19, KS20
2	Dumper	BEML	55 T	BD21, BD22, BD23
3	Dumper	Komatsu	55 T	KD24, KD25, KD26

5.3.3 Breakdown data of shovel-dumper system

The break down data (i.e., TBF: Time between failure and TTR: Time to repair) of the above mentioned shovel and dumper were collected for 4200 operating hours for one year. The detailed of breakdown hours and its causes of the shovel-dumper system in surface limestone mine were collected and given in Table A.3, Annexure-A. Also, details of failures of cause for each shovel and dumper were given in with cause for each shovel and dumper was given Section-C.1, Annexure-C and Section-C.2, Annexure-C respectively. The failure descriptions of each cause of shovel (Section-A, Annexure-C) and dumper (Section-B, Annexure-C) were explained briefly along with figures. Also, details of failure with cause for each shovel and dumper were given in Based on these failure data, the each shovel and dumper is categorized into 10 subsystems and all are connected in series. The subsystems of shovel and dumper and their failure codes are mentioned in Table 5.3. The detailed of breakdown hours and its causes of the shovel-dumper system in the surface coal mine were collected and given in Table A.1, Annexure-A.

5.3.4 Failure frequency

There are ten subsystems in each shovel (i.e., KS19 and KS20) and dumper (i.e., BD21, BD22, BD23, KD24, KD25 and KD26) and each subsystem having different failure frequency. Figure 5.3 shows that, clear view of the number of failures of subsystem (maximum failure of subsystems only) of each shovel and dumper. The failure frequency (in %) of each subsystems of shovel-dumper system were calculated and tabulated in Table. 5.12. The Table 5.12 clearly illustrated that, SS7 (Hydraulic subsystem) failed 28.79% and 24.29%

in KS19 and KS20 respectively. In case of dumpers, DS10 (Transmission subsystem) failed 25.27% and 28.87% in BD21 and BD22 respectively. Similarly, DS5 (Engine) failed 26.32%, 27.59%, 40.54% and 48.28% in BD23, KD24, KD25 and KD26 respectively. Since, SS7 (Steering subsystem) has failed frequently in both KS19 and KD20. Similarly, DS5 (Engine) has failed frequently in most of the dumpers and also more failure subsystem compared to others. With respect to number of failures KS19 (i.e., $N_{(KS19)}$=70) in case shovels and BD21 (i.e., $N_{(BD21)}$=91) in dumpers having number of more failures compared to other shovel and dumpers. Once information regarding failures and repair times is gathered and analyzed, MTBF, failure rate, MTTR and repair rate were determined and tabulated in Table 5.9.

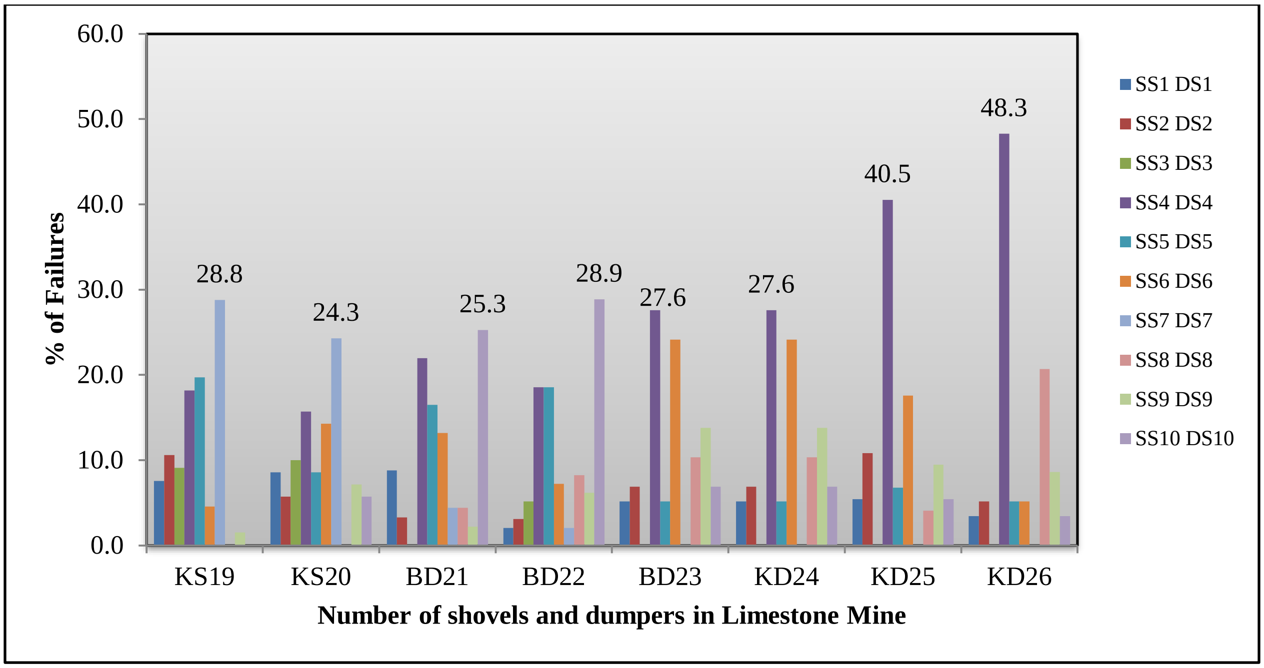


Figure 5.3 Percentage of failures in shovel and dumper in surface limestone mine

Table 5.12 Summary of No. failures of shovel-dumper system in surface limestone mine

SS's →		**SS1**	**SS2**	**SS3**	**SS4**	**SS5**	**SS6**	**SS7**	**SS8**	**SS9**	**SS10**	**N**
KS19	**n_1**	$n_{1(SS1)}$=5	$n_{1(SS2)}$=7	$n_{1(SS3)}$=6	$n_{1(SS4)}$=12	$n_{1(SS5)}$=13	$n_{1\ (SS6)}$=3	$n_{1\ (SS7)}$=19	$n_{1\ (SS8)}$=0	$n_{1(SS9)}$=1	$n_{1(SS10)}$=0	$N_{(KS19)}$=66
	%	7.576	10.61	9.091	18.18	19.7	4.545	28.79	0	1.515	0	100
KS20	**n_2**	$n_{2(SS1)}$=6	$n_{2\ (SS2)}$=4	$n_{2\ (SS3)}$=7	$n_{2\ (SS4)}$=11	$n_{2\ (SS5)}$=6	$n_{2\ (SS6)}$=10	$n_{2\ (SS7)}$=17	$n_{2\ (SS8)}$=0	$n_{2\ (SS9)}$=5	$n_{2\ (SS10)}$=4	$N_{(KS20)}$=70
	%	8.571	5.714	10	15.71	8.571	14.29	24.29	0	7.143	5.714	100
SS's →		**DS1**	**DS2**	**DS3**	**DS4**	**DS5**	**DS6**	**DS7**	**DS8**	**DS9**	**DS10**	**N**
BD21	**n_3**	$n_{3(DS1)}$=8	$n_{3\ (DS2)}$=3	$n_{3\ (DS3)}$=0	$n_{3\ (DS4)}$=20	$n_{3\ (DS5)}$=15	$n_{3\ (DS6)}$=12	$n_{3\ (DS7)}$=4	$n_{3\ (DS8)}$=4	$n_{3\ (DS9)}$=2	$n_{3\ (DS10)}$=23	$N_{(BD21)}$=91
	%	8.791	3.297	0	21.98	16.48	13.19	4.396	4.396	2.198	25.27	100
BD22	**n_4**	$n_{4(DS1)}$=2	$n_{4\ (DS2)}$=3	$n_{4\ (DS3)}$=5	$n_4 4_{(DS4)}$=18	$n_{4\ (DS5)}$=18	$n_{4\ (DS6)}$=7	$n_{4\ (DS7)}$=2	$n_{4\ (DS8)}$=8	$n_{4\ (DS9)}$=6	$n_{4\ (DS10)}$=28	$N_{(BD22)}$=97
	%	2.062	3.093	5.155	18.56	18.56	7.216	2.062	8.247	6.186	28.87	100
BD23	**n_5**	$n_{5(DS1)}$=9	$n_{5\ (DS2)}$=2	$n_{5\ (DS3)}$=2	$n_{5\ (DS4)}$=20	$n_{5\ (DS5)}$=19	$n_{5\ (DS6)}$=5	$n_{5\ (DS7)}$=0	$n_{5\ (DS8)}$=2	$n_{5\ (DS9)}$=3	$n_{5\ (DS10)}$=14	$N_{(BD23)}$=76
	%	11.84	2.632	2.632	26.32	25	6.579	0	2.632	3.947	18.42	100
KD24	**n_6**	$n_{6(DS1)}$=3	$n_{6\ (DS2)}$=4	$n_{6\ (DS3)}$=0	$n_{6\ (DS4)}$=16	$n_{6\ (DS5)}$=3	$n_{6\ (DS6)}$=14	$n_{6\ (DS7)}$=0	$n_{6\ (DS8)}$=6	$n_{6\ (DS9)}$=8	$n_{6\ (DS10)}$=4	$N_{(BD24)}$=58
	%	5.172	6.897	0	27.59	5.172	24.13793	0	10.34483	13.7931	6.896552	100
KD25	**n_7**	$n_{7(DS1)}$=4	$n_{7\ (D21)}$=8	$n_{7\ (DS3)}$=0	$n_{7\ (DS4)}$=30	$n_{7\ (DS5)}$=5	$n_{7\ (DS6)}$=13	$n_{7\ (DS7)}$=0	$n_{7\ (DS8)}$=3	$n_{7\ (DS9)}$=7	$n_{7\ (DS10)}$=4	$N_{(BD25)}$=74
	%	5.405	10.81	0	40.54	6.757	17.56757	0	4.054054	9.459459	5.40540	100
KD26	**n_8**	$n_{8(DS1)}$=2	$n_{8\ (DS2)}$=3	$n_{8\ (DS3)}$=0	$n_{8\ (DS4)}$=28	$n_{8\ (DS5)}$=3	$n_{8\ (DS6)}$=3	$n_{8\ (DS7)}$=0	$n_{8\ (DS8)}$=12	$n_{8\ (DS9)}$=5	$n_{8\ (DS10)}$=2	$N_{(BD26)}$=58
	%	3.448	5.172	0	48.28	5.172	5.172414	0	20.68966	8.62069	3.448276	100

Where, KS-Komastu Shovel, BD-BEML Dumper, KD-Komstu Shovel, SS's-Subsystem's, n_1, n_2, n_3.....are Number of failures of each subsystem, N-Total Number of failures in each shovel and dumper, $N=n_1+ n_{2+} n_{3+} n_{4+} n_{5+} n_{6+} n_7 +n_{8+} n_{9+} n_{10}$

Table 5.13 Failure and repair data of various subsystems of the dumper in the surface limestone mine

Systems↓	**SS's →**		**SS1**	**SS2**	**SS3**	**SS4**	**SS5**	**SS6**	**SS7**	**SS8**	**SS9**	**SS10**
KS19	**N**	$N_{(KS19)}=66$	$n_{1(SS1)}=5$	$n_{1(SS2)}=7$	$n_{1(SS3)}=6$	$n_{1(SS4)}=12$	$n_{1(SS5)}=13$	$n_{1\ (SS6)}=3$	$n_{1\ (SS7)}=19$	$n_{1\ (SS8)}=0$	$n_{1(SS9)}=1$	$n_{1(SS10)}=0$
	MTBF	91.061	816.319	517.0726	419.5307	481.8014	395.8507	1398.5	319.6546	0	2663.501	0
	λ	0.011	0.001225	0.001934	0.002384	0.002076	0.002526	0.000715	0.003128	0	0.000375	0
	MTTR	6.841	2.384	2.042857	9.511667	0.426667	1.014615	3.25	7.479474	0	0.065	0
	μ	0.26	0.419463	0.48951	0.105134	2.34375	0.985595	0.307692	0.133699	0	15.38462	0
KS20	**N**	$N_{(KS20)}=70$	$n_{2(SS1)}=6$	$n_{2\ (SS1)}=4$	$n_{2\ (SS1)}=7$	$n_{2\ (SS1)}=11$	$n_{2\ (SS1)}=6$	$n_{2\ (SS1)}=10$	$n_{2\ (SS1)}=17$	$n_{2\ (SS1)}=0$	$n_{2\ (SS1)}=5$	$n_{2\ (SS1)}=4$
	MTBF	83.692	920.5413	1360.088	824.0976	408.304	723.3472	571.7201	347.4922	0	872.2582	813.0708
	λ	0.012	0.001086	0.000735	0.001213	0.002449	0.001382	0.001749	0.002878	0	0.001146	0.00123
	MTTR	9.401	1.445	0.85	26.83	1.196364	0.985	1.871	4.877059	0	3.802	79.615
	μ	0.106	0.692042	1.176471	0.037272	0.835866	1.015228	0.534474	0.205042	0	0.263019	0.01256
Systems↓	**SS's →**		**DS1**	**DS2**	**DS3**	**DS4**	**DS5**	**DS6**	**DS7**	**DS8**	**DS9**	**DS10**
BD21	**N**	$N_{(BD21)}=91$	$n_{3(DS1)}=8$	$n_{3\ (DS2)}=3$	$n_{3\ (DS3)}=0$	$n_{3\ (DS4)}=20$	$n_{3\ (DS5)}=15$	$n_{3\ (DS6)}=12$	$n_{3\ (DS7)}=4$	$n_{3\ (DS8)}=4$	$n_{3\ (DS9)}=2$	$n_{3\ (DS10)}=23$
	MTBF	55.377	184.527	184.527	0	262.176	396.058	326.893	1075.949	1120.522	945.537	244.773
	λ	0.018	0.0054	0.0054	0.0000	0.0038	0.0025	0.0031	0.0009	0.0009	0.0011	0.0041
	MTTR	15.045	16.481	16.481	0	9.378	12.524	13.066	8.385	1.355	0.620	19.855
	μ	0.066	0.061	0.061	0	0.107	0.080	0.077	0.119	0.738	1.613	0.050
BD22	**N**	$N_{(BD22)}=97$	$n_{4(DS1)}=2$	$n_{4\ (DS2)}=3$	$n_{4\ (DS3)}=5$	$n_{4}4_{(DS4)}=18$	$n_{4\ (DS5)}=18$	$n_{4\ (DS6)}=7$	$n_{4\ (DS7)}=2$	$n_{4\ (DS8)}=8$	$n_{4\ (DS9)}=6$	$n_{4\ (DS10)}=28$
	MTBF	52.226	1099.996	1484.222	1092.533	263.205	292.185	716.046	1030.252	657.178	738.878	211.257
	λ	0.019	0.001	0.001	0.001	0.004	0.003	0.001	0.001	0.002	0.001	0.005
	MTTR	15.07	12.695	6.907	29.060	11.406	13.079	12.777	30.750	12.424	10.997	18.333
	μ	0.066	0.079	0.145	0.034	0.088	0.076	0.078	0.033	0.080	0.091	0.055
BD23	**N**	$N_{(BD23)}=76$	$n_{5(DS1)}=9$	$n_{5\ (DS2)}=2$	$n_{5\ (DS3)}=2$	$n_{5\ (DS4)}=20$	$n_{5\ (DS5)}=19$	$n_{5\ (DS6)}=5$	$n_{5\ (DS7)}=0$	$n_{5\ (DS8)}=2$	$n_{5\ (DS9)}=3$	$n_{5\ (DS10)}=14$
	MTBF	61.168	555.013	1766.752	1502.042	300.588	297.746	1239.329	0	1332.171	154.917	117.165
	λ	0.016	0.002	0.001	0.001	0.003	0.003	0.001	0	0.001	0.006	0.009
	MTTR	21.825	3.923	7.500	5.920	6.513	7.332	37.372	0	2.080	21.500	76.533
	μ	0.046	0.255	0.133	0.169	0.154	0.136	0.027	0	0.481	0.047	0.013

KD24	**N**	$N_{(BD24)}$=58	$n_{6(DS1)}$=3	$n_{6\,(DS2)}$=4	$n_{6\,(DS3)}$=0	$n_{6\,(DS4)}$=16	$n_{6\,(DS5)}$=3	$n_{6\,(DS6)}$=14	$n_{6\,(DS7)}$=0	$n_{6\,(DS8)}$=6	$n_{6\,(DS9)}$=8	$n_{6\,(DS10)}$=4
	MTBF	83.703	518.973	370.500	0	72.014	413.339	306.795	0	479.990	479.990	555.751
	λ	0.012	0.002	0.003	0	0.014	0.002	0.003	0	0.002	0.002	0.002
	MTTR	7.486	22.720	4.145	0	3.500	19.320	3.280	0	5.179	5.179	41.813
	μ	0.134	0.044	0.241	0	0.286	0.052	0.305	0	0.193	0.193	0.024
KD25	**N**	$N_{(KD25)}$=74	$n_{7(DS1)}$=4	$n_{7\,(D21)}$=8	$n_{7\,(DS3)}$=0	$n_{7\,(DS4)}$=30	$n_{7\,(DS5)}$=5	$n_{7\,(DS6)}$=13	$n_{7\,(DS7)}$=0	$n_{7\,(DS8)}$=3	$n_{7\,(DS9)}$=7	$n_{7\,(DS10)}$=4
	MTBF	80.085	1378.417	596.658	0	186.826	345.469	322.776	0	1390.441	719.175	1568.709
	λ	0.012	0.001	0.002	0	0.005	0.003	0.003	0	0.001	0.001	0.001
	MTTR	8.907	74.958	2.843	0	1.998	8.264	10.884	0	6.893	10.207	2.700
	μ	0.112	0.013	0.352	0	0.500	0.121	0.092	0	0.145	0.098	0.370
KD26	**N**	$N_{(KD26)}$=58	$n_{8(DS1)}$=2	$n_{8\,(DS2)}$=3	$n_{8\,(DS3)}$=0	$n_{8\,(DS4)}$=28	$n_{8\,(DS5)}$=3	$n_{8\,(DS6)}$=3	$n_{8\,(DS7)}$=0	$n_{8\,(DS8)}$=12	$n_{8\,(DS9)}$=5	$n_{8\,(DS10)}$=2
	MTBF	93.714	2351.001	1291.892	0	209.390	1592.550	1190.342	0	490.378	428.842	415.333
	λ	0.011	0.0004	0.001	0	0.005	0.001	0.001	0	0.002	0.002	0.002
	MTTR	10.031	4.500	14.933	0	3.008	12.953	7.100	0	4.664	5.170	150.905
	μ	0.1	0.222	0.067	0	0.332	0.077	0.141	0	0.214	0.193	0.007

CHAPTER 6

STATISTICAL ANALYSIS

6.1 Determination of TBF, TTR, CTBF and CTTR

6.1.1 Surface coal mine

After sorting and classification of collected historical failure data of shovel-dumper system in surface coal mine (which are given in Table A.1, Annexure-A), the number of failure and numbers of times failed is identified and also, TBF and TTR of each shovel and dumper is calculated for 5400 working hours. To verify the IID assumption of collected failure data, the TBFs and TTRs need to be sorted and arranged sequentially. Also, the cumulative TBFs and TTRs. The TBF, TTR, cumulative failure frequency (CFF), cumulative TBF (CTBF), and cumulative TTR (CTTR) for each shovel i.e., KS1 & KS2 are calculated and tabulated in Table 6.1. Similarly, the Table 6.2, Table 6.3, Table 6.4 and Table 6.5 shows that the calculated TBF, TTR, CFF, CTBF, and CTTR of dumpers i.e., BD3 & BD4 in Table 6.2, BD5 & BD6 in Table 6.3, KD7 and KD8 in Table 6.4, and KD9 & KD10 in Table 6.5 respectively.

Table 6.1 TBF, TTR, CTBF, and CTTR for each subsystem of KS1 and KS2

KS1					**KS2**				
Sl. NO	TBF , hr	CTBF, hr	TTR, hr	CTTR, hr	Sl. NO	TBF, hr	CTBF, hr	TTR, hr	CTTR, hr
1	0.00	0.00	0.20	0.20	1	0.00	0.00	48.50	48.50
2	17.30	17.30	5.53	5.73	2	15.52	15.52	0.02	48.52
3	8.47	25.77	2.75	8.48	3	7.97	23.48	5.75	54.27
4	6.76	32.53	7.99	16.47	4	0.50	23.98	4.00	58.27
5	12.51	45.03	9.25	25.72	5	12.75	36.73	1.50	59.77
6	9.25	54.28	2.77	28.49	6	15.50	52.23	4.76	64.53
7	7.24	61.52	5.76	34.25	7	27.74	79.98	1.75	66.28
8	50.74	112.26	7.33	41.58	8	13.75	93.73	113.51	179.79
9	8.17	120.43	4.76	46.34	9	6.99	100.72	4.50	184.29
10	7.40	127.84	1.33	47.67	10	3.00	103.72	3.75	188.04
11	14.25	142.09	0.92	48.59	11	2.75	106.47	3.51	191.55
12	19.83	161.92	2.75	51.34	12	14.01	120.48	99.99	291.54
13	55.67	217.59	0.42	51.76	13	143.24	263.72	0.92	292.46

14	2.67	220.25	1.83	53.59	14	14.02	277.73	0.49	292.95
15	51.42	271.67	0.09	53.68	15	26.67	304.40	0.57	293.52
16	6.66	278.33	3.25	56.93	16	4.25	308.65	0.50	294.02
17	19.92	298.24	0.17	57.10	17	47.25	355.90	8.83	302.85
18	0.42	298.66	4.00	61.10	18	16.26	372.16	0.33	303.18
19	16.00	314.66	5.58	66.68	19	118.16	490.32	6.25	309.43
20	27.42	342.08	1.08	67.76	20	81.27	571.59	4.15	313.58
21	13.17	355.24	0.33	68.09	21	58.68	630.27	140.15	453.73
22	1.83	357.08	2.67	70.76	22	15.50	645.78	1.50	455.23
23	1.17	358.24	2.50	73.26	23	12.16	657.94	0.17	455.40
24	101.17	459.41	0.33	73.59	24	98.17	756.11	1.00	456.40
25	13.50	472.91	0.50	74.09	25	5.50	761.61	2.00	458.40
26	107.00	579.91	2.75	76.84	26	25.92	787.52	4.92	463.32
27	353.27	933.18	11.98	88.82	27	65.33	852.86	1.08	464.40
28	13.50	946.68	0.50	89.32	28	17.25	870.11	5.67	470.07
29	17.00	963.68	10.67	99.99	29	90.58	960.69	3.25	473.32
30	10.83	974.51	0.75	100.74	30	33.01	993.70	0.16	473.48
31	4.75	979.26	0.50	101.24	31	16.32	1010.03	1.42	474.90
32	80.25	1059.51	0.08	101.32	32	12.42	1022.44	3.67	478.57
33	154.68	1214.19	9.48	110.80	33	5.00	1027.44	7.52	486.09
34	0.00	1214.19	16.33	127.13	34	15.90	1043.34	1.08	487.17
35	12.68	1226.88	3.48	130.61	35	21.50	1064.84	3.67	490.84
36	15.25	1242.13	6.93	137.54	36	25.35	1090.19	28.98	519.82
37	40.32	1282.45	1.75	139.29	37	19.25	1109.44	15.75	535.57
38	45.08	1327.53	0.67	139.96	38	5.02	1114.46	1.32	536.89
39	1.83	1329.37	0.42	140.38	39	46.66	1161.13	2.50	539.39
40	11.67	1341.03	4.08	144.46	40	93.00	1254.13	3.17	542.56
41	2.50	1343.53	6.33	150.79	41	19.33	1273.46	9.00	551.56
42	1.17	1344.70	21.00	171.79	42	44.50	1317.96	8.75	560.31
43	3.00	1347.70	17.25	189.04	43	0.08	1318.04	0.25	560.56
44	3.50	1351.20	3.25	192.29	44	0.42	1318.46	0.33	560.89
45	19.33	1370.53	2.17	194.46	45	5.18	1323.64	0.50	561.39
46	27.75	1398.28	0.25	194.71	46	11.99	1335.63	5.00	566.39
47	61.00	1459.28	1.50	196.21	47	10.02	1345.64	34.42	600.81
48	2.52	1461.80	5.65	201.86	48	40.32	1385.96	2.00	602.81
49	14.83	1476.63	2.17	204.03	49	24.08	1410.05	0.67	603.48
50	18.85	1495.48	3.98	208.01	50	3.50	1413.55	0.34	603.82
51	20.02	1515.50	4.65	212.66	51	16.91	1430.45	8.75	612.57
52	20.83	1536.33	15.67	228.33	52	58.00	1488.45	0.17	612.74
53	9.67	1546.00	1.00	229.33	53	1.08	1489.54	0.08	612.82
54	22.50	1568.50	1.00	230.33	54	34.17	1523.70	2.25	615.07

55	39.77	1608.27	3.73	234.06	55	23.50	1547.20	1.08	616.15
56	0.33	1608.60	1.17	235.23	56	84.67	1631.87		616.15
57	58.00	1666.60	1.00	236.23	57	5.000	1636.87	24.00	640.15
58	69.00	1735.60	3.17	239.40	58	29.17	1666.04	0.33	640.48
59	0.33	1735.94	0.25	239.65	59	23.00	1689.04	0.25	640.73
60	50.67	1786.60	0.42	240.07	60	135.25	1824.29	4.25	644.98
61	65.67	1852.27	2.51	242.58	61	0.170	1824.45	0.58	645.56
62	60.99	1913.27	1.42	244.00	62	96.75	1921.21	3.58	649.14
63	66.10	1979.37	1.23	245.23	63	30.17	1951.37	1.00	650.14
64	41.25	2020.62	8.17	253.40	64	72.50	2023.87	0.25	650.39
65	51.84	2072.46	1.99	255.39	65	13.75	2037.62	138.25	788.64
66	80.00	2152.45	0.08	255.47	66	0.420	2038.04	3.58	792.22
67	137.42	2289.87	15.83	271.30	67	49.77	2087.81	1.48	793.70
68	11.17	2301.04	0.17	271.47	68	2.330	2090.14	3.58	797.28
69	89.83	2390.87	9.42	280.89	69	11.33	2101.47	3.25	800.53
70	155.58	2546.45	0.25	281.14	70	20.25	2121.72	0.50	801.03
71	9.75	2556.20	2.50	283.64	71	2.750	2124.47	0.08	801.11
72	34.00	2590.20	1.33	284.97	72	24.17	2148.64	0.75	801.86
73	1.17	2591.37	4.00	288.97	73	11.50	2160.14	0.50	802.36
74	36.17	2627.54	6.83	295.80	74	14.01	2174.15	3.25	805.61
75	45.50	2673.04	30.25	326.05	75	4.230	2178.39	1.75	807.36
76	17.75	2690.79	3.00	329.05	76	37.92	2216.30	2.35	809.71
77	16.75	2707.54	5.25	334.30	77	19.24	2235.54	25.02	834.73
78	29.75	2737.29	1.33	335.63	78	12.24	2247.77	0.50	835.23
79	4.93	2742.22	0.42	336.05	79	23.00	2270.77	0.50	835.73
80	3.58	2745.80	0.33	336.38	80	19.50	2290.27	3.50	839.23
81	43.67	2789.47	0.34	336.72	81	89.83	2380.11	2.33	841.56
82	7.65	2797.12	0.75	337.47	82	185.83	2565.94	4.50	846.06
83	46.75	2843.87	15.50	352.97	83	13.52	2579.46	0.98	847.04
84	298.51	3142.38	3.66	356.63	84	0.33	2579.79	1.83	848.87
85	2.34	3144.72	6.48	363.11	85	96.83	2676.62	0.25	849.12
86	68.08	3212.81	1.25	364.36	86	20.27	2696.89	5.23	854.35
87	138.42	3351.22	0.42	364.78	87	71.08	2767.97	3.92	858.27
88	4.17	3355.40	0.17	364.95	88	11.25	2779.22	7.35	865.62
89	52.99	3408.39	6.33	371.28	89	81.74	2860.96	1.08	866.70
90	1.68	3410.07	2.48	373.76	90	162.58	3023.54	1.50	868.20
91	58.17	3468.24	0.33	374.09	91	8.09	3031.63	1.01	869.21
92	19.50	3487.74	0.85	374.94	92	1.41	3033.04	0.58	869.79
93	63.15	3550.89	1.00	375.94	93	25.16	3058.20	3.00	872.79
94	12.00	3562.89	0.67	376.61	94	189.01	3247.21	5.17	877.96
95	51.33	3614.22	0.33	376.94	95	7.65	3254.87	8.17	886.13

96	6.67	3620.89	0.76	377.70	96	4.52	3259.38	33.48	919.61
97	19.57	3640.46	4.92	382.62	97	85.00	3344.38	27.00	946.61
98	2.11	3642.57	1.64	384.26	98	120.83	3465.22	5.01	951.62
99	27.50	3670.07	1.00	385.26	99	1.00	3466.22	1.67	953.29
100	17.25	3687.32	4.08	389.34	100	65.07	3531.29	3.25	956.54
101	9.17	3696.49	0.34	389.68	101	82.67	3613.96	3.25	959.79
102	30.33	3726.82	2.66	392.34	102	20.08	3634.04	11.50	971.29
103	3.67	3730.49	2.00	394.34	103	84.66	3718.70	0.50	971.79
104	34.50	3764.99	0.83	395.17	104	43.17	3761.87	4.83	976.62
105	54.68	3819.67	2.23	397.40	105	0.25	3762.12	13.75	990.37
106	20.75	3840.42	0.17	397.57	106	18.25	3780.37	3.67	994.04
107	7.84	3848.26	0.50	398.07	107	14.34	3794.71	0.58	994.62
108	15.01	3863.27	63.50	461.57	108	57.00	3851.70	0.50	995.12
109	0.99	3864.26	1.00	462.57	109	28.00	3879.70	0.33	995.45
110	7.77	3872.02	1.23	463.80	110	24.00	3903.70	0.33	995.78
111	0.58	3872.61	0.42	464.22	111	85.52	3989.22	3.65	999.43
112	0.17	3872.77	2.33	466.55	112	11.83	4001.05	1.00	1000.43
113	6.67	3879.44	3.17	469.72	113	2.17	4003.22	1.50	1001.93
114	9.17	3888.62	13.48	483.20	114	6.33	4009.55	4.33	1006.26
115	44.00	3932.62	1.00	484.20	115	62.17	4071.72	1.00	1007.26
116	23.75	3956.37	0.58	484.78	116	44.25	4115.97	0.08	1007.34
117	8.00	3964.37	65.67	550.45	117	13.67	4129.64	2.75	1010.09
118	22.17	3986.53	7.17	557.62	118	86.26	4215.90	6.74	1016.83
119	59.58	4046.11	0.33	557.95	119	98.00	4313.90	0.25	1017.08
120	45.75	4091.86	3.00	560.95	120	97.84	4411.74	0.92	1018.00
121	25.50	4117.36	7.50	568.45	121	36.91	4448.65	0.25	1018.25
122	8.50	4125.86	0.50	568.95	122	94.83	4543.48	0.08	1018.33
123	15.01	4140.87	1.84	570.79	123	2.00	4545.48	31.67	1050.00
124	53.67	4194.54	11.31	582.10	124	24.00	4569.48	2.17	1052.17
125	15.42	4209.97	1.92	584.02	125	15.35	4584.83	2.48	1054.65
126	4.33	4214.30	4.50	588.52	126	25.50	4610.33	0.75	1055.40
127	2.52	4216.82	2.73	591.25	127	6.92	4617.25	23.58	1078.98
128	13.26	4230.07	4.01	595.26	128	20.25	4637.50	2.75	1081.73
129	0.75	4230.83	2.25	597.51	129	17.75	4655.25	0.75	1082.48
130	0.58	4231.40	4.91	602.42	130	17.67	4672.91	3.33	1085.81
131	29.75	4261.15	0.25	602.67	131	1.08	4674.00	3.17	1088.98
132	1.33	4262.49	3.58	606.25	132	21.67	4695.66	1.33	1090.31
133	10.58	4273.07	0.50	606.75	133	1.42	4697.08	0.33	1090.64
134	113.50	4386.57	6.50	613.25	134	2.25	4699.33	0.75	1091.39
135	21.00	4407.57	67.75	681.00	135	172.00	4871.33	35.75	1127.14
136	17.25	4424.82	9.17	690.17	136	0.02	4871.35	0.23	1127.37

137	7.84	4432.67	5.16	695.33	137	17.75	4889.10	0.75	1128.12
138	11.58	4444.25	1.00	696.33	138	23.77	4912.86	0.15	1128.27
139	13.25	4457.50	3.75	700.08	139	126.02	5038.88	7.07	1135.34
140	1.50	4459.00	0.50	700.58	140	50.25	5089.13	0.25	1135.59
141	13.75	4472.75	9.00	709.58	141	9.43	5098.56	4.83	1140.42
142	2.50	4475.25	0.33	709.91	142	5.92	5104.47	4.58	1145.00
143	5.26	4480.51	2.41	712.32	143	123.00	5227.48	0.25	1145.25
144	4.99	4485.51	4.25	716.57	144	132.42	5359.89	0.75	1146.00
145	18.52	4504.02	0.31	716.88	145	4.09	5363.98	0.50	1146.50
146	29.44	4533.46	0.90	717.78	146	35.99	5399.98	2.50	1149.00
147	1.75	4535.21	1.51	719.29	147	12.75	5412.73	2.00	1151.00
148	61.66	4596.87	0.08	719.37	148	14.75	5427.48	4.33	1155.33
149	5.92	4602.79	0.42	719.79	149	9.18	5436.66	1.75	1157.08
150	23.77	4626.55	8.48	728.27	150	39.33	5475.99	2.41	1159.49
151	0.17	4626.72	2.83	731.10	151	4.99	5480.99	4.25	1163.74
152	17.83	4644.55	1.67	732.77	152	762.52	6243.50	0.31	1164.05
153	71.75	4716.30	0.08	732.85	153	29.44	6272.94	0.90	1164.95
154	27.42	4743.72	6.79	739.64	154	673.75	6946.69	1.51	1166.46
155	34.96	4778.68	2.50	742.14	155	61.66	7008.35	0.08	1166.54
156	5.00	4783.68	0.17	742.31	156	5.92	7014.27	0.42	1166.96
157	1.83	4785.52	0.25	742.56	157	767.77	7782.03	8.48	1175.44
158	40.00	4825.52	0.50	743.06	-	-	-	-	-
159	0.25	4825.77	0.33	743.39	-	-	-	-	-
160	26.92	4852.68	0.25	743.64	-	-	-	-	-
161	0.08	4852.77	0.25	743.89	-	-	-	-	-
162	7.67	4860.43	0.67	744.56	-	-	-	-	-
163	14.92	4875.35	0.33	744.89	-	-	-	-	-
164	11.58	4886.93	1.50	746.39	-	-	-	-	-
165	58.00	4944.93	0.50	746.89	-	-	-	-	-
166	15.33	4960.27	2.42	749.31	-	-	-	-	-
167	33.25	4993.52	0.75	750.06	-	-	-	-	-
168	3.75	4997.27	6.75	756.81	-	-	-	-	-
169	64.92	5062.18	5.50	762.31	-	-	-	-	-
170	0.50	5062.68	26.33	788.64	-	-	-	-	-
171	58.50	5121.18	12.26	800.90	-	-	-	-	-
172	270.74	5391.92	5.00	805.90	-	-	-	-	-
173	12.50	5404.42	9.58	815.48	-	-	-	-	-
174	9.43	5413.86	4.48	819.96	-	-	-	-	-
175	758.25	6172.11	7.75	827.71	-	-	-	-	-
176	62.00	6234.11	1.00	828.71	-	-	-	-	-
177	728.02	6962.12	1.48	830.19	-	-	-	-	-

178	49.76	7011.88	2.94	833.13	-	-	-	-	-
179	95.30	7107.19	6.33	839.46	-	-	-	-	-
180	792.17	7899.35	5.17	844.63	-	-	-	-	-
181	34.58	7933.94	4.76	849.39	-	-	-	-	-

Table 6.2 TBF, TTR, CTBF, and CTTR for each subsystem of BD3 and BD4

BD3					**BD4**				
Sl. NO	TBF, hr	CTBF, hr	TTR, hr	CTTR, hr	Sl. NO	TBF, hr	CTBF, hr	TTR, hr	CTTR, hr
1	0.00	0.00	85.13	92.13	1	0.00	0.00	2.68	2.68
2	146.18	146.18	109.82	201.95	2	452.52	452.52	5.40	8.08
3	322.63	468.81	5.93	207.88	3	547.47	999.99	23.70	31.78
4	115.87	584.68	2.57	210.45	4	215.35	1215.34	6.00	37.78
5	282.66	867.34	822.34	1032.79	5	567.07	1782.41	11.25	49.03
6	142.63	1009.97	20.42	1053.21	6	354.67	2137.08	2.57	51.60
7	357.45	1367.42	3.00	1056.21	7	34.85	2171.93	2.00	53.60
8	438.31	1805.73	9.49	1065.70	8	42.67	2214.60	0.17	53.77
9	106.50	1912.23	15.71	1081.41	9	93.67	2308.26	357.50	411.27
10	108.04	2020.27	12.16	1093.57	10	0.87	2309.14	23.34	434.61
11	109.59	2129.86	13.00	1106.57	11	4.79	2313.93	0.26	434.87
12	86.00	2215.86	1.00	1107.57	12	88.75	2402.68	1.76	436.63
13	61.00	2276.86	20.38	1127.95	13	20.48	2423.16	3.22	439.85
14	28.12	2304.99	15.13	1143.08	14	4.53	2427.69	17.69	457.54
15	32.37	2337.35	20.37	1163.45	15	6.31	2434.01	160.18	617.72
16	137.14	2474.49	2.64	1166.09	16	13.07	2447.08	14.75	632.47
17	44.69	2519.18	1.17	1167.26	17	17.21	2464.29	6.48	638.95
18	132.01	2651.19	13.56	1180.82	18	25.32	2489.61	47.23	686.18
19	47.93	2699.12	5.28	1186.10	19	0.75	2490.36	23.50	709.68
20	16.30	2715.42	2.42	1188.52	20	116.00	2606.36	27.50	737.18
21	2.42	2717.84	2.78	1191.30	21	19.00	2625.36	4.58	741.76
22	159.64	2877.48	7.40	1198.70	22	137.92	2763.28	3.06	744.82
23	253.77	3131.25	0.50	1199.20	23	238.44	3001.73	5.50	750.32
24	78.50	3209.75	2.97	1202.17	24	66.50	3068.23	5.09	755.41
25	43.03	3252.78	1.00	1203.17	25	208.42	3276.64	8.00	763.41
26	128.00	3380.78	18.03	1221.20	26	16.50	3293.14	127.50	890.91
27	48.47	3429.25	3.52	1224.72	27	189.71	3482.85	0.18	891.09
28	8.98	3438.23	13.50	1238.22	28	0.61	3483.47	0.25	891.34
29	73.50	3511.73	19.50	1257.72	29	765.57	4249.03	0.01	891.35
30	7.00	3518.73	43.24	1300.96	30	0.05	4249.08	6.00	897.35
31	260.76	3779.49	4.00	1304.96	31	0.10	4249.18	0.13	897.48
32	125.33	3904.82	0.25	1305.21	32	2.39	4251.57	24.51	921.99
33	49.92	3954.74	0.50	1305.71	33	499.74	4751.31	4.25	926.24

34	8.50	3963.24	1.26	1306.97	34	163.50	4914.81	4.51	930.75
35	329.24	4292.48	0.33	1307.30	35	43.95	4958.76	4.66	935.41
36	7.67	4300.15	4.00	1311.30	36	3.39	4962.14	3.00	938.41
37	95.20	4395.35	1.30	1312.60	37	12.00	4974.14	5.89	944.30
38	410.50	4805.85	0.50	1313.10	38	8.11	4982.25	15.65	959.95
39	90.75	4896.60	3.25	1316.35	39	136.35	5118.60	30.50	990.45
40	40.75	4937.35	54.75	1371.10	40	139.00	5257.60	6.01	996.46
41	41.50	4978.85	0.50	1371.60	41	0.49	5258.09	23.00	1019.46
42	2.00	4980.85	1.44	1373.04	42	41.50	5299.59	414.12	1433.58
43	148.06	5128.90	23.21	1396.25	43	28.02	5327.61	16.86	1450.44
44	83.29	5212.19	7.50	1403.75	44	165.00	5492.61	8.00	1458.44
45	64.50	5276.69	9.01	1412.76	45	264.25	5756.86	21.75	1480.19
46	43.83	5320.52	4.18	1416.94	46	77.50	5834.36	19.95	1500.14
50	136.25	5632.61	35.00	1491.83	-	-	-	-	-
51	0.90	5633.52	377.51	1869.34	-	-	-	-	-
52	24.02	5657.53	6.06	1875.40	-	-	-	-	-
53	31.92	5689.46	16.00	1891.40	-	-	-	-	-
54	316.58	6006.04	6.00	1897.40	-	-	-	-	-
55	138.93	6144.97	16.80	1914.20	-	-	-	-	-
56	21.75	6166.72	2.17	1916.37	-	-	-	-	-

Table 6.3 TBF, TTR, CTBF, and CTTR for each subsystem of BD5 and BD6

BD5					**BD6**				
Sl. NO	TBF, hr	CTBF, hr	TTR, hr	CTTR, hr	Sl. NO	TBF, hr	CTBF, hr	TTR, hr	CTTR, hr
1	0.00	0.00	0.17	0.17	1	0.00	0.00	4.35	4.35
2	451.45	451.45	4.13	4.30	2	21.08	21.08	0.51	4.86
3	66.87	518.33	5.10	9.40	3	189.83	210.91	3.74	8.60
4	79.61	597.93	9.00	18.40	4	72.09	283.00	0.44	9.04
5	384.92	982.85	1.09	19.49	5	117.11	400.11	4.33	13.37
6	46.64	1029.49	6.11	25.60	6	82.46	482.57	1.25	14.62
7	234.44	1263.93	670.81	696.41	7	46.53	529.10	180.22	194.84
8	124.56	1388.49	0.44	696.85	8	28.50	557.60	18.18	213.02
9	213.38	1601.87	2.62	699.47	9	40.32	597.91	6.09	219.11
10	356.25	1958.12	5.00	704.47	10	6.91	604.83	0.50	219.61
11	194.25	2152.37	0.50	704.97	11	4.83	609.66	1.67	221.28
12	6.00	2158.37	15.50	720.47	12	57.00	666.66	1.00	222.28
13	1.75	2160.12	44.05	764.52	13	5.05	671.71	22.46	244.74
14	214.71	2374.83	4.00	768.52	14	164.50	836.21	2.50	247.24
15	11.49	2386.31	324.69	1093.21	15	11.00	847.20	13.78	261.02
16	478.31	2864.62	25.50	1118.71	16	18.72	865.92	4.10	265.12
17	161.57	3026.20	76.25	1194.96	17	18.41	884.33	3.99	269.11

18	59.17	3085.37	15.00	1209.96	18	68.00	952.33	7.00	276.11
19	1.50	3086.87	43.33	1253.29	19	56.50	1008.83	12.69	288.80
20	96.67	3183.54	1.50	1254.79	20	43.33	1052.16	6.98	295.78
21	54.50	3238.04	19.33	1274.12	21	12.01	1064.17	5.99	301.77
22	428.17	3666.21	1.35	1275.47	22	37.84	1102.01	11.75	313.52
23	70.95	3737.16	3.26	1278.73	23	169.41	1271.42	3.74	317.26
24	18.80	3755.96	1.14	1279.87	24	474.26	1745.69	28.46	345.72
25	56.50	3812.45	1.00	1280.87	25	339.04	2084.73	21.51	367.23
26	11.75	3824.20	30.82	1311.69	26	115.49	2200.22	5.47	372.70
27	208.43	4032.63	5.39	1317.08	27	16.02	2216.24	5.00	377.70
28	245.61	4278.25	14.21	1331.29	28	2.24	2218.48	24.25	401.95
29	208.79	4487.03	6.29	1337.58	29	327.51	2545.99	8.00	409.95
30	17.71	4504.74	0.17	1337.75	30	65.50	2611.49	6.50	416.45
31	57.33	4562.07	4.10	1341.85	31	169.02	2780.51	22.98	439.43
32	74.40	4636.47	21.56	1363.41	32	49.50	2830.01	21.50	460.93
33	186.44	4822.91	4.00	1367.41	33	84.00	2914.01	13.50	474.43
34	46.97	4869.88	2.53	1369.94	34	48.48	2962.49	22.52	496.95
35	4.00	4873.88	43.50	1413.44	35	383.50	3345.99	2.07	499.02
36	22.50	4896.38	70.81	1484.25	36	90.68	3436.67	27.75	526.77
37	27.69	4924.07	8.51	1492.76	37	65.50	3502.17	6.67	533.44
38	138.49	5062.55	17.65	1510.41	38	145.83	3648.01	22.52	555.96
39	146.78	5209.33	23.57	1533.98	39	501.98	4149.99	1.83	557.79
40	0.71	5210.05	0.49	1534.47	40	89.67	4239.66	27.05	584.84
41	22.80	5232.84	26.00	1560.47	41	86.45	4326.11	9.00	593.84
-	-	-	-	-	42	220.88	4546.99	23.69	617.53
-	-	-	-	-	43	71.89	4618.88	23.55	641.08
-	-	-	-	-	44	42.00	4660.88	6	647.08
-	-	-	-	-	45	235.50	4896.38	2.25	649.33

Table 6.4 TBF, TTR, CTBF, and CTTR for each subsystem of KD7 and KD8

KD7					**KD8**				
Sl. NO	TBF, hr	CTBF, hr	TTR, hr	CTTR, hr	Sl. NO	TBF, hr	CTBF, hr	TTR, hr	CTTR, hr
1	0.00	0.00	56.71	56.71	1	0.00	0.00	1.94	1.94
2	46.75	46.75	4.33	61.04	2	14.76	14.76	9.24	11.18
3	1.67	48.42	121.50	182.54	3	9.50	24.26	0.50	11.68
4	22.08	70.50	2.17	184.71	4	22.00	46.26	2.75	14.43
5	23.25	93.75	14.50	199.21	5	278.75	325.01	2.50	16.93
6	3.75	97.50	8.82	208.03	6	10.50	335.51	14.75	31.68
7	43.18	140.68	44.08	252.11	7	27.76	363.27	6.15	37.83
8	176.67	317.35	1.00	253.11	8	65.10	428.37	31.07	68.90
9	49.50	366.85	2.17	255.28	9	65.67	494.04	1.67	70.57

10	3.33	370.18	1.50	256.78	10	8.50	502.54	9.83	80.40
11	99.50	469.68	24.92	281.70	11	114.00	616.54	0.83	81.23
12	0.58	470.27	2.17	283.87	12	7.17	623.70	11.75	92.98
13	39.33	509.60	204.50	488.37	13	36.75	660.45	7.01	99.99
14	12.00	521.60	0.33	488.70	14	31.49	691.94	1.50	101.49
15	23.17	544.77	13.25	501.95	15	12.00	703.94	15.50	116.99
16	394.00	938.77	36.26	538.21	16	6.50	710.44	0.25	117.24
17	52.49	991.26	0.25	538.46	17	39.25	749.69	1.00	118.24
18	47.75	1039.01	0.42	538.88	18	22.50	772.19	5.75	123.99
19	223.58	1262.59	8.50	547.38	19	194.01	966.20	0.49	124.48
20	71.50	1334.09	26.01	573.39	20	8.91	975.11	46.00	170.48
21	27.00	1361.09	0.91	574.30	21	56.67	1031.78	7.17	177.65
22	44.84	1405.93	17.24	591.54	22	35.11	1066.89	4.72	182.37
23	221.83	1627.77	13.67	605.21	23	10.17	1077.06	15.25	197.62
24	0.50	1628.27	28.50	633.71	24	49.75	1126.81	5.25	202.87
25	6.17	1634.43	29.76	663.47	25	0.08	1126.89	1.83	204.70
26	91.66	1726.10	1.03	664.50	26	129.50	1256.39	20.08	224.78
27	178.40	1904.49	1.50	666.00	27	106.58	1362.97	4.75	229.53
28	49.49	1953.98	0.02	666.02	28	146.17	1509.14	6.00	235.53
29	37.48	1991.47	0.83	666.85	29	68.75	1577.89	0.33	235.86
30	9.67	2001.13	13.83	680.68	30	37.33	1615.22	36.29	272.15
31	141.37	2142.50	2.55	683.23	31	38.54	1653.76	10.75	282.90
32	35.75	2178.25	6.76	689.99	32	183.75	1837.51	2.25	285.15
33	10.74	2189.00	12.02	702.01	33	123.92	1961.43	18.83	303.98
34	102.73	2291.73	324.25	1026.26	34	39.50	2000.93	6.92	310.90
35	51.50	2343.23	24.50	1050.76	35	25.58	2026.51	1.50	312.40
36	21.00	2364.23	1.25	1052.01	36	65.67	2092.18	4.68	317.08
37	1.26	2365.49	0.50	1052.51	37	17.15	2109.33	2.17	319.25
38	15.66	2381.15	1.33	1053.84	38	1.83	2111.16	9.17	328.42
39	110.50	2491.65	0.42	1054.26	39	31.42	2142.58	8.93	337.35
40	175.08	2666.73	1.00	1055.26	40	14.48	2157.06	10.50	347.85
41	39.50	2706.23	2.33	1057.59	41	21.26	2178.33	0.80	348.65
42	23.93	2730.16	22.15	1079.74	42	2.19	2180.52	6.00	354.65
43	67.01	2797.17	0.58	1080.32	43	20.08	2200.60	6.17	360.82
44	40.49	2837.67	7.00	1087.32	44	6.51	2207.11	1.33	362.15
45	20.51	2858.18	8.24	1095.56	45	58.91	2266.02	4.25	366.40
46	8.58	2866.76	63.50	1159.06	46	0.33	2266.35	12.68	379.08
47	26.67	2893.43	1.00	1160.06	47	2.98	2269.34	4.00	383.08
48	4.01	2897.43	1.25	1161.31	48	4.00	2273.34	0.75	383.83
49	22.75	2920.18	0.49	1161.80	49	32.75	2306.09	1.33	385.16
50	60.99	2981.18	16.35	1178.15	50	10.33	2316.42	2.83	387.99

51	282.15	3263.33	2.33	1180.48	51	42.75	2359.17	4.58	392.57
52	43.17	3306.50	8.17	1188.65	52	11.17	2370.34	7.50	400.07
53	34.50	3341.00	35.83	1224.48	53	15.00	2385.34	7.83	407.90
54	6.17	3347.16	0.33	1224.81	54	15.17	2400.50	1.50	409.40
55	37.02	3384.18	0.98	1225.79	55	24.75	2425.25	6.42	415.82
56	147.50	3531.68	16.00	1241.79	56	10.27	2435.53	35.06	450.88
57	27.51	3559.19	149.99	1391.78	57	12.58	2448.11	0.42	451.30
58	2.02	3561.21	9.15	1400.93	58	27.67	2475.78	8.82	460.12
59	86.33	3647.54	9.43	1410.36	59	42.52	2518.29	29.50	489.62
60	54.57	3702.11	9.50	1419.86	60	19.84	2538.14	4.41	494.03
61	0.33	3702.45	7.92	1427.78	61	12.24	2550.38	1.00	495.03
62	30.25	3732.70	6.50	1434.28	62	61.50	2611.88	18.00	513.03
63	108.00	3840.70	9.34	1443.62	63	11.50	2623.38	0.83	513.86
64	5.66	3846.35	2.25	1445.87	64	18.17	2641.55	5.75	519.61
65	17.25	3863.60	20.76	1466.63	65	123.26	2764.81	1.00	520.61
66	13.49	3877.09	19.75	1486.38	66	19.00	2783.80	38.91	559.52
67	246.00	4123.09	1.00	1487.38	67	27.58	2811.39	1.00	560.52
68	74.83	4197.92	13.91	1501.29	68	4.50	2815.89	1.00	561.52
69	70.26	4268.18	8.59	1509.88	69	6.52	2822.40	2.48	564.00
70	15.41	4283.59	4.50	1514.38	70	1.00	2823.40	1.33	565.33
71	59.50	4343.09	34.50	1548.88	71	5.17	2828.57	7.08	572.41
72	29.51	4372.59	0.75	1549.63	72	11.42	2839.99	5.18	577.59
73	39.74	4412.34	31.76	1581.39	73	2.09	2842.07	46.24	623.83
74	10.74	4423.08	13.42	1594.81	74	14.01	2856.08	1.32	625.15
75	11.51	4434.59	2.58	1597.39	75	7.65	2863.73	0.12	625.27
76	33.50	4468.09	0.53	1597.92	76	17.40	2881.13	0.33	625.60
77	41.80	4509.89	8.00	1605.92	77	69.67	2950.80	2.00	627.60
78	28.67	4538.56	5.50	1611.42	78	192.50	3143.30	5.00	632.60
79	108.50	4647.06	16.25	1627.67	79	384.02	3527.32	1.98	634.58
80	25.75	4672.81	2.33	1630.00	80	23.00	3550.32	1.50	636.08
81	293.26	4966.07	8.17	1638.17	81	95.83	3646.15	0.17	636.25
82	268.99	5235.07	35.83	1674.00	82	35.18	3681.33	9.99	646.24
83	162.52	5397.58	0.33	1674.33	83	14.33	3695.66	35.50	681.74
84	101.44	5499.02	0.98	1675.31	84	8.50	3704.16	12.75	694.49
85	25.75	5524.77	16.00	1691.31	85	16.75	3720.91	2.50	696.99
86	277.66	5802.43	149.99	1841.30	86	38.50	3759.41	48.67	745.66
87	53.92	5856.35	9.15	1850.45	87	8.25	3767.66	1.25	746.91
88	71.77	5928.11	9.43	1859.88	88	21.83	3789.49	1.00	747.91
-	-	-	-	-	92	68.59	3923.58	2.91	760.33
-	-	-	-	-	93	43.75	3967.33	9.58	769.91
-	-	-	-	-	94	103.58	4070.91	10.58	780.49

-	-	-	-	-	95	68.52	4139.43	1.15	781.64
-	-	-	-	-	96	22.85	4162.28	1.32	782.96
-	-	-	-	-	97	53.68	4215.96	4.49	787.45
-	-	-	-	-	98	12.99	4228.95	0.50	787.95
-	-	-	-	-	99	14.50	4243.45	16.50	804.45
-	-	-	-	-	100	71.84	4315.29	3.49	807.94
-	-	-	-	-	101	9.17	4324.45	1.00	808.94
-	-	-	-	-	102	83.50	4407.95	3.00	811.94
-	-	-	-	-	103	121.50	4529.45	0.50	812.44
-	-	-	-	-	104	107.83	4637.29	5.17	817.61
-	-	-	-	-	105	111.67	4748.95	0.33	817.94
-	-	-	-	-	106	61.00	4809.95	3.50	821.44
-	-	-	-	-	107	10.26	4820.22	7.74	829.18
-	-	-	-	-	108	7.00	4827.22	1.00	830.18
-	-	-	-	-	109	25.33	4852.55	0.58	830.76
-	-	-	-	-	110	37.58	4890.13	0.50	831.26
-	-	-	-	-	111	2.33	4892.47	3.67	834.93
-	-	-	-	-	112	22.00	4914.47	0.50	835.43
-	-	-	-	-	113	26.50	4940.97	12.00	847.43
-	-	-	-	-	114	0.75	4941.72	4.58	852.01
-	-	-	-	-	115	9.01	4950.73	6.66	858.67
-	-	-	-	-	116	28.83	4979.56	8.67	867.34
-	-	-	-	-	117	39.50	5019.06	2.26	869.60
-	-	-	-	-	118	23.75	5042.81	5.34	874.94
-	-	-	-	-	119	14.90	5057.71	5.27	880.21
-	-	-	-	-	120	1.49	5059.20	5.41	885.62
-	-	-	-	-	121	63.08	5122.29	1.00	886.62
-	-	-	-	-	122	25.00	5147.29	5.50	892.12
-	-	-	-	-	123	29.50	5176.79	5.17	897.29
-	-	-	-	-	124	22.33	5199.12	8.75	906.04
-	-	-	-	-	125	15.25	5214.37	1.50	907.54
-	-	-	-	-	126	46.51	5260.87	12.49	920.03
-	-	-	-	-	127	82.00	5342.87	0.75	920.78
-	-	-	-	-	128	11.75	5354.62	29.25	950.03
-	-	-	-	-	129	52.67	5407.29	0.75	950.78
-	-	-	-	-	130	109.84	5517.13	0.49	951.27
-	-	-	-	-	131	97.50	5614.63	4.00	955.27
-	-	-	-	-	132	206.50	5821.13	13.06	968.33
-	-	-	-	-	133	54.73	5875.85	3.39	971.72
-	-	-	-	-	134	408.83	6284.68	2.00	973.72
-	-	-	-	-	135	145.40	6430.08	5.74	979.46

-	-	-	-	-	136	284.98	6715.07	7.54	987.00
-	-	-	-	-	137	135.80	6850.87	8.25	995.25
-	-	-	-	-	138	148.82	6999.69	14.49	1009.74
-	-	-	-	-	139	363.56	7363.25	10.50	1020.24
-	-	-	-	-	140	44.12	7407.37	0.25	1020.49
-	-	-	-	-	141	73.60	7480.96	13.24	1033.73

Table 6.5 TBF, TTR, CTBF, and CTTR for each subsystem of KD9 and KD10

KD9					**KD10**				
Sl. NO	TBF, hr	CTBF, hr	TTR, hr	CTTR, hr	Sl. NO	TBF, hr	CTBF, hr	TTR, hr	CTTR, hr
1	0.00	0.00	25.53	25.53	1	0.00	0.00	10.49	10.49
2	65.51	65.51	8.66	34.19	2	55.99	55.99	1.25	11.74
3	17.58	83.09	3.00	37.19	3	56.75	112.74	1.50	13.24
4	138.26	221.35	1.01	38.20	4	31.51	144.25	7.99	21.23
5	50.16	271.51	6.82	45.02	5	3.17	147.42	9.84	31.07
6	71.75	343.26	18.58	63.60	6	31.99	179.41	4.50	35.57
7	30.35	373.61	0.11	63.71	7	6.33	185.75	18.42	53.99
8	104.21	477.82	7.50	71.21	8	18.75	204.50	4.33	58.32
9	1.77	479.59	17.48	88.69	9	5.33	209.83	5.42	63.74
10	146.75	626.34	0.67	89.36	10	9.92	219.75	4.50	68.24
11	34.08	660.43	2.75	92.11	11	5.33	225.08	0.67	68.91
12	20.83	681.26	6.33	98.44	12	62.00	287.08	1.33	70.24
13	39.83	721.09	1.50	99.94	13	2.50	289.58	3.18	73.42
14	138.00	859.09	26.97	126.91	14	17.32	306.90	5.42	78.84
15	21.53	880.63	2.75	129.66	15	44.08	350.98	4.00	82.84
16	2.75	883.38	7.00	136.66	16	8.67	359.65	15.00	97.84
17	31.01	914.38	5.01	141.67	17	45.07	404.72	10.59	108.43
18	5.99	920.37	21.25	162.92	18	14.09	418.81	3.25	111.68
19	1.25	921.62	4.83	167.75	19	0.25	419.06	30.75	142.43
20	121.68	1043.30	0.57	168.32	20	0.52	419.58	83.98	226.41
21	39.92	1083.22	2.50	170.82	21	14.59	434.16	12.66	239.07
22	19.00	1102.22	34.00	204.82	22	1.75	435.91	7.67	246.74
23	35.00	1137.22	1.25	206.07	23	7.33	443.24	0.75	247.49
24	43.27	1180.49	10.98	217.05	24	1.75	444.99	3.00	250.49
25	5.02	1185.50	16.00	233.05	25	5.75	450.74	5.26	255.75
26	40.48	1225.99	0.02	233.07	26	7.51	458.25	6.82	262.57
27	5.50	1231.49	23.33	256.40	27	2.67	460.92	7.01	269.58
28	67.15	1298.64	1.00	257.40	28	0.25	461.17	11.74	281.32
29	23.00	1321.64	0.67	258.07	29	22.83	484.00	7.17	288.49
30	15.33	1336.97	1.17	259.24	30	66.75	550.75	0.33	288.82
31	30.33	1367.30	5.00	264.24	31	10.42	561.17	16.02	304.84

32	1.00	1368.31	7.75	271.99	32	28.49	589.66	13.24	318.08
33	61.50	1429.81	2.25	274.24	33	55.25	644.91	1.00	319.08
34	11.01	1440.81	0.59	274.83	34	4.50	649.41	3.00	322.08
35	167.40	1608.22	12.50	287.33	35	33.33	682.74	38.25	360.33
36	21.50	1629.72	6.51	293.84	36	2.58	685.33	2.83	363.16
37	7.49	1637.21	0.67	294.51	37	1.00	686.33	12.26	375.42
38	7.33	1644.54	0.50	295.01	38	0.66	686.99	3.25	378.67
39	210.50	1855.04	132.50	427.51	39	0.82	687.81	9.51	388.18
40	2.02	1857.06	7.98	435.49	40	10.99	698.81	1.50	389.68
41	54.50	1911.56	8.50	443.99	41	21.17	719.98	0.50	390.18
42	17.50	1929.06	6.50	450.49	42	33.08	753.06	7.25	397.43
43	9.66	1938.72	10.00	460.49	43	113.50	866.56	31.00	428.43
44	18.67	1957.39	8.50	468.99	44	143.17	1009.73	5.85	434.28
45	68.67	2026.06	7.75	476.74	45	150.49	1160.21	1.50	435.78
46	92.25	2118.31	4.33	481.07	46	42.75	1202.96	12.75	448.53
47	44.28	2162.58	7.47	488.54	47	51.75	1254.71	6.25	454.78
48	0.08	2162.67	10.83	499.37	48	85.00	1339.71	0.75	455.53
49	13.01	2175.67	0.33	499.70	49	95.25	1434.96	6.50	462.03
50	10.83	2186.50	6.33	506.03	50	17.50	1452.46	0.50	462.53
51	158.50	2345.00	13.17	519.20	51	175.50	1627.96	2.50	465.03
52	45.09	2390.09	0.17	519.37	52	256.50	1884.46	4.00	469.03
53	48.07	2438.17	0.75	520.12	53	41.00	1925.46	6.50	475.53
54	28.75	2466.92	0.75	520.87	54	209.51	2134.97	0.50	476.03
55	210.50	2677.42	16.50	537.37	55	53.49	2188.46	5.00	481.03
56	47.25	2724.67	8.50	545.87	56	13.00	2201.46	128.67	609.70
57	7.50	2732.17	21.33	567.20	57	31.33	2232.79	0.58	610.28
58	54.67	2786.84	10.51	577.71	58	231.42	2464.21	2.00	612.28
59	39.99	2826.82	0.75	578.46	59	158.00	2622.21	2.25	614.53
60	1.75	2828.57	4.50	582.96	60	3.42	2625.63	6.33	620.86
61	3.50	2832.07	2.72	585.68	61	141.52	2767.14	18.65	639.51
62	6.53	2838.60	43.42	629.10	62	7.60	2774.74	19.57	659.08
63	10.33	2848.94	4.33	633.43	63	1.67	2776.42	1.41	660.49
64	82.92	2931.85	0.58	634.01	64	17.58	2793.99	1.50	661.99
65	5.17	2937.02	8.00	642.01	65	3.01	2797.00	19.37	681.36
66	5.00	2942.02	0.75	642.76	66	79.78	2876.79	0.33	681.69
67	114.75	3056.77	0.50	643.26	67	53.33	2930.12	17.17	698.86
68	14.26	3071.03	5.99	649.25	68	104.84	3034.96	0.17	699.03
69	18.01	3089.04	9.24	658.49	69	206.66	3241.62	29.00	728.03
70	64.67	3153.71	56.33	714.82	70	57.33	3298.96	38.40	766.43
71	6.50	3160.21	0.58	715.40	71	0.05	3299.01	115.95	882.38
72	79.42	3239.62	0.50	715.90	72	0.03	3299.04	439.48	1321.86

73	23.50	3263.12	0.50	716.40	73	0.02	3299.06	113.67	1435.53
74	24.58	3287.71	4.59	720.99	74	3.50	3302.56	0.67	1436.20
75	97.82	3385.53	4.25	725.24	75	6.85	3309.41	0.74	1436.94
76	108.25	3493.78	7.75	732.99	76	10.00	3319.40	6.00	1442.94
77	17.50	3511.28	3.25	736.24	77	8.75	3328.15	3.83	1446.77
78	52.00	3563.28	8.34	744.58	78	32.42	3360.57	21.75	1468.52
79	63.17	3626.46	8.41	752.99	79	22.00	3382.57	3.75	1472.27
80	66.51	3692.97	22.66	775.65	80	0.92	3383.49	2.83	1475.10
81	38.92	3731.88	0.17	775.82	81	1.17	3384.65	22.33	1497.43
82	100.85	3832.73	3.48	779.30	82	0.50	3385.15	19.17	1516.60
83	65.75	3898.48	1.75	781.05	83	2.33	3387.49	2.00	1518.60
84	135.76	4034.24	14.24	795.29	84	79.50	3466.99	9.17	1527.77
85	0.17	4034.41	14.83	810.12	85	38.83	3505.82	0.83	1528.60
86	94.02	4128.43	4.48	814.60	86	48.17	3553.99	16.25	1544.85
87	4.01	4132.44	1.08	815.68	87	25.75	3579.74	2.33	1547.18
88	1.41	4133.86	0.24	815.92	88	293.26	3873.00	8.17	1555.35
89	79.75	4213.61	0.44	816.36	89	604.99	4477.99	35.83	1591.18
90	138.78	4352.38	2.62	818.98	90	162.52	4640.51	0.33	1591.51
91	9.50	4361.88	5.00	823.98	91	437.44	5077.95	0.98	1592.49
92	39.25	4401.13	0.50	824.48	92	1.75	5079.70	16.00	1608.49
93	371.00	4772.13	15.50	839.98	93	277.66	5357.36	149.99	1758.48
94	203.33	4975.46	44.05	884.03	94	509.92	5867.28	9.15	1767.63
95	622.00	5597.46	4.00	888.03	95	71.77	5939.04	9.43	1777.06
96	26.80	5624.26	324.69	1212.72	-	-	-	-	-
97	67.01	5691.27	25.50	1238.22	-	-	-	-	-

6.1.2 Surface iron ore mine

In surface Iron ore mine also, sorting and classification of collected historical failure data of shovel-dumper system in surface coal mine (which are given in Table A.2, Annexure-A), the number of failure and numbers of times failed is identified and also, TBF and TTR of each shovel and dumper is calculated for 3900 working hours. To verify the IID assumption of collected failure data, the TBFs and TTRs needs to be sorted and arranged sequentially. Also, the cumulative TBFs and cumulative TTRs. The TBF, TTR, Cumulative failure frequency (CFF), Cumulative TBF (CTBF), and Cumulative TTR (CTTR) for each shovel i.e., KS11 and KS12 are tabulated in Table 6.6. Similarly, Table 6.7 and Table 6.8 shows the TBF, TTR, CFF, CTBF, and CTTR of dumpers i.e., BD13 & BD14 in Table 6.7 and BD15, KD16, KD17 and KD18 in Table 6.8 respectively.

Table 6.6 TBF, TTR, CTBF, and CTTR for each subsystem of KS11 and KS12

KS11					**KS12**				
Sl. NO	TBF, hr	CTBF, hr	TTR, hr	CTTR, hr	Sl. NO	TBF, hr	CTBF, hr	TTR, hr	CTTR, hr
1	0	0	0.02	0.02	1	0	0	7.83	7.83
2	121.26	121.26	0.08	0.10	2	87.18	87.18	1.65	9.48
3	45.50	166.76	4.50	4.60	3	2.08	89.27	2.80	12.28
4	645.50	812.26	1.00	5.60	4	116.67	205.94	3.17	15.45
5	445.01	1257.27	10.49	16.09	5	18.82	224.76	0.17	15.62
6	269.50	1526.77	2.00	18.09	6	292.83	517.59	5.00	20.62
7	30.50	1557.27	0.75	18.84	7	32.75	550.35	1.00	21.62
8	79.26	1636.53	35.99	54.83	8	2.50	552.84	1.25	22.87
9	490.50	2127.03	63.83	118.66	9	10.83	563.68	1.17	24.04
10	469.42	2596.45	3.00	121.66	10	10.00	573.68	3.75	27.79
11	258.75	2855.20	1.50	123.16	11	24.08	597.76	3.90	31.69
12	30.51	2885.71	14.50	137.66	12	29.00	626.76	0.50	32.19
13	52.49	2938.20	11.50	149.16	13	0.83	627.59	9.20	41.39
14	16.75	2954.95	19.75	168.91	14	1.58	629.18	6.00	47.39
15	60.00	3014.95	0.17	169.08	15	20.33	649.51	4.00	51.39
16	4.18	3019.13	0.03	169.11	16	2.00	651.51	6.00	57.39
17	196.62	3215.75	4.00	173.11	17	16.17	667.68	8.20	65.59
18	15.50	3231.25	3.25	176.36	18	19.50	687.18	4.60	70.19
19	493.25	3724.50	2.75	179.11	19	8.85	696.02	2.00	72.19
20	103.25	3827.75	29.45	208.56	20	37.50	733.52	5.90	78.09
21	73.40	3901.15	20.30	228.86	21	2.60	736.12	4.07	82.16
22	20.86	3922.01	6.98	235.84	22	2.26	738.38	2.08	84.24
23	21.75	3943.77	25.25	261.09	23	11.75	750.13	8.51	92.75
24	27.50	3971.27	21.00	282.09	24	122.49	872.62	1.75	94.50
25	650.01	4621.27	0.50	282.59	25	168.00	1040.6	2.00	96.50
26	17.83	4639.10	20.18	302.77	26	46.08	1086.7	2.75	99.25
27	4.98	4644.08	29.00	331.77	27	351.42	1438.1	3.00	102.25
28	18.00	4662.08	3.50	335.27	28	27.75	1465.8	1.80	104.05
29	856.75	5518.83	1.75	337.02	29	256.18	1722.0	2.50	106.55
30	273.00	5791.83	4.50	341.52	-	-	-	-	-
31	67.25	5859.08	1.75	343.27	-	-	-	-	-

Table 6.7 TBF, TTR, CTBF, and CTTR for each subsystem of BD13 and BD14

BD13					**BD14**				
Sl. NO	TBF, hr	CTBF, hr	TTR, hr	CTTR, hr	Sl. NO	TBF, hr	CTBF, hr	TTR, hr	CTTR, hr
1	0	0.00	37.00	37.00	1	0.00	0.00	35.17	35.17
2	114.33	114.33	1.17	38.17	2	21.33	21.33	5.25	40.42
3	47.67	162.00	0.50	38.67	3	65.75	87.08	2.00	42.42

4	68.00	230.00	146.33	185.00	4	7.00	94.08	1.50	43.92
5	0.83	230.83	95.17	280.17	5	35.00	129.08	3.67	47.59
6	241.00	471.83	20.00	300.17	6	68.33	197.42	1.00	48.59
7	442.83	914.67	2.17	302.33	7	10.00	207.42	21.00	69.59
8	66.00	980.67	1.33	303.67	8	220.00	427.42	0.50	70.09
9	44.17	1024.83	0.50	304.17	9	139.75	567.17	2.75	72.84
10	193.42	1218.25	1.25	305.42	10	97.50	664.67	5.50	78.34
11	23.33	1241.58	1.50	306.92	11	6.00	670.67	24.00	102.34
12	104.50	1346.08	171.00	477.92	12	0.00	670.67	33.17	135.50
13	249.75	1595.83	0.42	478.33	13	96.83	767.50	1.67	137.17
14	159.83	1755.67	1.83	480.17	14	120.17	887.67	23.17	160.34
15	29.58	1785.25	4.58	484.75	15	243.83	1131.50	0.50	160.84
16	34.00	1819.25	5.50	490.25	16	26.92	1158.42	1.00	161.84
17	49.33	1868.58	18.17	508.42	17	52.25	1210.67	0.75	162.59
18	14.00	1882.58	0.50	508.92	18	181.50	1392.17	0.58	163.17
19	43.00	1925.58	17.00	525.92	19	253.67	1645.83	1.17	164.34
20	1.33	1926.92	0.92	526.83	20	37.33	1683.17	24.00	188.34
21	92.75	2019.67	0.50	527.33	21	0.00	1683.17	19.50	207.84
22	35.25	2054.92	1.33	528.67	22	217.17	1900.33	1.15	208.99
23	594.42	2649.33	16.50	545.17	23	4.10	1904.43	1.08	210.07
24	131.00	2780.33	37.00	582.17	24	79.75	1984.18	1.25	211.32
25	195.50	2975.83	2.50	584.67	25	20.50	2004.68	3.00	214.32
26	38.50	3014.33	25.00	609.67	26	57.67	2062.35	26.17	240.49
27	104.00	3118.33	0.50	610.17	27	27.42	2089.77	0.50	240.99
28	20.50	3138.83	2.50	612.67	28	143.33	2233.10	25.25	266.24
29	19.33	3158.17	1.17	613.83	29	42.83	2275.93	3.33	269.57
30	114.00	3272.17	7.00	620.83	30	64.75	2340.68	29.25	298.82
31	92.50	3364.67	0.50	621.33	31	27.00	2367.68	1.00	299.82
32	134.50	3499.17	37.50	658.83	32	67.00	2434.68	21.75	321.57
33	19.50	3518.67	5.00	663.83	33	129.75	2564.43	0.33	321.90
34	144.50	3663.17	6.00	669.83	34	63.75	2628.18	1.42	323.32
35	129.00	3792.17	2.00	671.83	35	46.08	2674.27	1.00	324.32
36	58.50	3850.67	5.50	677.33	36	284.92	2959.18	0.25	324.57
37	87.00	3937.67	6.50	683.83	37	253.75	3212.93	2.50	327.07
38	6.50	3944.17	24.00	707.83	38	145.75	3358.68	1.75	328.82
39	120.50	4064.67	2.50	710.33	39	22.00	3380.68	4.00	332.82
40	21.00	4085.67	30.67	741.00	40	210.50	3591.18	30.00	362.82
41	46.83	4132.50	11.50	752.50	41	78.00	3669.18	11.50	374.32
42	97.00	4229.50	24.00	776.50	42	69.50	3738.68	6.50	380.82
43	0.00	4229.50	400.50	1177.00	43	41.50	3780.18	1.00	381.82
44	157.50	4387.00	17.00	1194.00	44	22.00	3802.18	7.00	388.82

45	164.00	4551.00	19.00	1213.00	45	16.00	3818.18	9.00	397.82
46	0.00	4551.00	151.00	1364.00	46	152.00	3970.18	1.00	398.82
47	39.50	4590.50	4.50	1368.50	47	73.00	4043.18	4.50	403.32
48	2.50	4593.00	206.50	1575.00	48	96.50	4139.68	1.17	404.49
49	53.50	4646.50	3.00	1578.00	49	0.00	4139.68	0.83	405.32
50	68.00	4714.50	11.00	1589.00	50	7.00	4146.68	4.00	409.32
51	340.50	5055.00	11.00	1600.00	51	42.50	4189.18	5.00	414.32
52	2.00	5057.00	18.25	1618.25	52	112.50	4301.68	1.00	415.32
53	29.25	5086.25	9.00	1627.25	53	4.75	4306.43	6.25	421.57
54	217.50	5303.75	12.00	1639.25	54	78.00	4384.43	2.00	423.57
55	549.00	5852.75	334.50	1973.75	55	65.50	4449.93	10.00	433.57
56	214.00	6066.75	22.50	1996.25	56	45.25	4495.18	1.75	435.32
57	285.00	6351.75	5.75	2002.00	57	49.50	4544.68	36.00	471.32
58	154.75	6506.50	18.00	2020.00	58	48.00	4592.68	8.00	479.32
59	16.50	6523.00	6.00	2026.00	59	82.00	4674.68	14.00	493.32
60	30.75	6553.75	14.75	2040.75	60	64.00	4738.68	1.00	494.32
61	159.50	6713.25	16.50	2057.25	61	54.50	4793.18	4.50	498.82
62	228.50	6941.75	14.50	2071.75	62	130.00	4923.18	13.50	512.32
63	48.00	6989.75	5.50	2077.25	63	36.50	4959.68	24.00	536.32
64	34.00	7023.75	3.00	2080.25	64	267.00	5226.68	7.00	543.32
-	-	-	-	-	65	8.00	5234.68	164.50	707.82
-	-	-	-	-	66	83.50	5318.18	31.50	739.32
-	-	-	-	-	67	6.00	5324.18	68.50	807.82
-	-	-	-	-	68	99.50	5423.68	44.00	851.82
-	-	-	-	-	69	112.83	5536.52	4.67	856.49
-	-	-	-	-	70	5.58	5542.10	42.42	898.90
-	-	-	-	-	71	80.00	5622.10	1.00	899.90
-	-	-	-	-	72	6.00	5628.10	13.00	912.90
-	-	-	-	-	73	20.00	5648.10	7.00	919.90
-	-	-	-	-	74	14.00	5662.10	72.58	992.49
-	-	-	-	-	75	9.92	5672.02	13.00	1005.49
-	-	-	-	-	76	329.50	6001.52	7.00	1012.49
-	-	-	-	-	77	42.00	6043.52	13.00	1025.49
-	-	-	-	-	78	37.00	6080.52	6.50	1031.99
-	-	-	-	-	79	874.50	6955.02	17.00	1048.99
-	-	-	-	-	80	9.50	6964.52	80.50	1129.49
-	-	-	-	-	81	31.00	6995.52	19.33	1148.82
-	-	-	-	-	82	46.17	7041.68	2.00	1150.82
-	-	-	-	-	83	47.50	7089.18	7.50	1158.32
-	-	-	-	-	84	1.50	7090.68	59.00	1217.32
-	-	-	-	-	85	438.00	7528.68	29.00	1246.32

-	-	-	-	-	86	29.00	7557.68	9.50	1255.82
-	-	-	-	-	87	166.50	7724.18	3.83	1259.65
-	-	-	-	-	88	227.67	7951.85	5.50	1265.15

Table 6.8 TBF, TTR, CTBF and CTTR for each subsystem of BD15, KD16, KD17 and KD18

BD15					**KD16**				
Sl. NO	TBF, hr	CTBF, hr	TTR, hr	CTTR, hr	Sl. NO	TBF, hr	CTBF, hr	TTR, hr	CTTR, hr
1	0.00	0.00	37.00	37.00	1	0.00	0.00	7.50	7.50
2	44.67	44.67	1.83	38.83	2	737.50	737.50	543.00	550.50
3	96.50	141.17	0.75	39.58	3	164.00	901.50	192.00	742.50
4	77.75	218.92	11.33	50.92	4	262.00	1163.50	2.00	744.50
5	8.25	227.17	0.50	51.42	5	120.00	1283.50	21.00	765.50
6	69.42	296.58	12.00	63.42	6	676.33	1959.83	18.67	784.17
7	204.50	501.08	0.50	63.92	7	508.00	2467.83	24.50	808.67
8	12.33	513.42	1.17	65.08	8	445.50	2913.33	32.00	840.67
9	198.50	711.92	28.50	93.58	9	570.33	3483.67	24.00	864.67
10	118.50	830.42	0.42	94.00	10	212.17	3695.83	3.50	868.17
11	217.25	1047.67	2.83	96.83	11	9.50	3705.33	257.50	1125.67
12	61.00	1108.67	4.33	101.17	12	197.00	3902.33	6.00	1131.67
13	29.17	1137.83	1.50	102.67	13	0.00	3902.33	18.50	1150.17
14	33.00	1170.83	12.50	115.17	14	430.33	4332.67	295.17	1445.33
15	262.33	1433.17	23.17	138.33	15	661.00	4993.67	2.67	1448.00
16	1.50	1434.67	2.75	141.08	16	136.33	5130.00	3.75	1451.75
17	157.75	1592.42	3.50	144.58	17	173.75	5303.75	2.50	1454.25
18	32.33	1624.75	1.83	146.42	18	549.50	5853.25	23.00	1477.25
19	21.17	1645.92	13.17	159.58	19	523.00	6376.25	29.50	1506.75
20	15.92	1661.83	1.08	160.67	20	112.00	6488.25	52.00	1558.75
21	40.00	1701.83	1.83	162.50	**KD17**				
22	85.92	1787.75	2.25	164.75	1	0.00	0.00	25.25	25.25
23	149.50	1937.25	4.50	169.25	2	854.25	854.25	11.50	36.75
24	7.50	1944.75	7.50	176.75	3	280.00	1134.25	52.50	89.25
25	64.75	2009.50	39.75	216.50	4	76.50	1210.75	20.00	109.25
26	0.00	2009.50	33.75	250.25	5	95.00	1305.75	3.00	112.25
27	22.25	2031.75	40.67	290.92	6	409.25	1715.00	19.42	131.67
28	17.00	2048.75	10.58	301.50	7	220.75	1935.75	410.58	542.25
29	13.58	2062.33	1.17	302.67	8	340.75	2276.50	26.75	569.00
30	25.50	2087.83	50.00	352.67	9	238.00	2514.50	23.50	592.50
31	49.67	2137.50	10.83	363.50	10	715.50	3230.00	19.50	612.00
32	50.00	2187.50	6.00	369.50	11	483.00	3713.00	23.75	635.75
33	221.50	2409.00	1.25	370.75	12	598.00	4311.00	24.25	660.00
34	14.25	2423.25	51.25	422.00	13	510.00	4821.00	42.00	702.00

35	25.17	2448.42	37.33	459.33	14	486.50	5307.50	24.00	726.00
36	214.42	2662.83	0.25	459.58	15	23.50	5331.00	342.50	1068.50
37	205.42	2868.25	18.17	477.75	16	40.00	5371.00	481.50	1550.00
38	162.67	3030.92	0.83	478.58	17	283.33	5654.33	24.00	1574.00
39	92.25	3123.17	2.25	480.83	18	13.00	5667.33	7.17	1581.17
40	350.00	3473.17	206.00	686.83	19	717.50	6384.83	17.50	1598.67
41	50.00	3523.17	20.50	707.33	**KD18**				
42	79.50	3602.67	3.75	711.08	1	0.00	0.00	313.00	313.00
43	6.25	3608.92	7.00	718.08	2	426.67	426.67	26.67	339.67
44	52.75	3661.67	1.00	719.08	3	186.00	612.67	7.00	346.67
45	251.25	3912.92	4.00	723.08	4	219.00	831.67	21.00	367.67
46	48.00	3960.92	12.00	735.08	5	5.25	836.92	21.42	389.08
47	32.00	3992.92	5.00	740.08	6	951.83	1788.75	2.50	391.58
48	47.00	4039.92	24.00	764.08	7	266.00	2054.75	14.00	405.58
49	0.00	4039.92	27.00	791.08	8	297.00	2351.75	24.00	429.58
50	58.00	4097.92	2.00	793.08	9	65.00	2416.75	33.00	462.58
51	41.00	4138.92	76.00	869.08	10	253.00	2669.75	6.75	469.33
52	128.00	4266.92	29.00	898.08	11	140.75	2810.50	6.50	475.83
53	208.00	4474.92	24.00	922.08	12	533.50	3344.00	10.50	486.33
54	24.00	4498.92	45.00	967.08	13	71.00	3415.00	6.50	492.83
55	486.00	4984.92	10.00	977.08	14	16.50	3431.50	12.00	504.83
56	298.00	5282.92	65.00	1042.08	15	594.50	4026.00	5.25	510.08
57	131.00	5413.92	5.50	1047.58	16	216.25	4242.25	20.00	530.08
58	310.50	5724.42	22.25	1069.83	17	172.25	4414.50	18.25	548.33
59	13.75	5738.17	37.00	1106.83	18	198.50	4613.00	20.00	568.33
60	43.00	5781.17	5.00	1111.83	19	476.00	5089.00	5.50	573.83
61	91.00	5872.17	10.00	1121.83	20	360.75	5449.75	19.75	593.58
62	18.00	5890.17	4.00	1125.83	21	287.42	5737.17	47.58	641.17
63	0.00	5890.17	0.00	1125.83	22	476.00	6213.17	33.50	674.67
64	44.00	5934.17	2.00	1127.83	23	402.75	6615.92	3.75	678.42
65	34.00	5968.17	3.50	1131.33	24	25.00	6640.92	23.00	701.42
66	20.50	5988.67	18.00	1149.33	25	432.50	7073.42	271.50	972.92
67	0.00	5988.67	1.00	1150.33	26	0.00	7073.42	8.00	980.92
68	53.50	6042.17	10.50	1160.83	27	99.00	7172.42	7.00	987.92
69	14.00	6056.17	10.00	1170.83	-	-	-	-	-
70	180.25	6236.42	14.58	1185.42	-	-	-	-	-
71	54.17	6290.58	0.50	1185.92	-	-	-	-	-
72	67.75	6358.33	3.00	1188.92	-	-	-	-	-
73	1072.75	7431.08	3.50	1192.42	-	-	-	-	-
74	234.75	7665.83	7.75	1200.17	-	-	-	-	-
75	487.50	8153.33	2.50	1202.67	-	-	-	-	-

76	124.00	8277.33	7.00	1209.67	-	-	-	-	-
77	198.50	8475.83	3.50	1213.17	-	-	-	-	-

6.1.3 Surface limestone mine

In surface limestone mine, sorting and classification of collected historical failure data of shovel-dumper system in surface coal mine (which are given in Table A.3, Annexure-A), the number of failure and numbers of times failed is identified and also, TBF and TTR of each shovel and dumper is calculated for 4200 working hours. To verify the IID assumption of collected failure data, the TBFs and TTRs needs to be sorted and arranged sequentially. Also, the cumulative TBFs and cumulative TTRs. The TBF, TTR, Cumulative failure frequency (CFF), CTBF and CTTR for each shovel i.e., KS19 & KS20 tabulated in Table 6.9. Similarly, Table 6.14, Table 6.15, and Table 6.16 shows the TBF, TTR, CFF, CTBF and CTTR of dumpers i.e., BD21 & BD22 in Table 6.10, BD23 and KD24 in Table 6.11 and KD25 and KD26 in Table 6.12 respectively.

Table 6.9 TBF, TTR, CTBF, and CTTR for each subsystem of KS21 and KS22

KS21					**KS22**				
Sl. NO	TBF, hr	CTBF, hr	TTR, hr	CTTR, hr	Sl. NO	TBF, hr	CTBF, hr	TTR, hr	CTTR, hr
1	0	0	0.08	0.08	1	0.00	0.00	12	12
2	335.17	335.17	0.08	0.16	2	212.00	212.00	3.25	15.25
3	171.17	506.33	0.5	0.66	3	77.25	289.25	0.75	16
4	357.75	864.08	1	1.66	4	6.75	296.00	1.33	17.33
5	142.25	1006.33	0.25	1.91	5	82.50	378.50	6.92	24.25
6	262.75	1269.08	3.5	5.41	6	30.27	408.77	2.32	26.57
7	62.02	1331.10	0.98	6.39	7	54.58	463.35	1.92	28.49
8	225.17	1556.27	0.5	6.89	8	593.18	1056.53	1	29.49
9	244.08	1800.35	0.17	7.06	9	283.49	1340.02	0.17	29.66
10	1.58	1801.93	0.5	7.56	10	48.35	1388.37	2.23	31.89
11	201.58	2003.52	5.67	13.23	11	20.77	1409.14	0.98	32.87
12	58.86	2062.38	0.73	13.96	12	0.75	1409.89	0.17	33.04
13	0.17	2062.54	0.25	14.21	13	13.10	1422.99	17.98	51.02
14	3.24	2065.78	1	15.21	14	88.10	1511.09	1.4	52.42
15	166.77	2232.55	2.23	17.44	15	7.92	1519.00	0.5	52.92
16	1.30	2233.85	0.2	17.64	16	443.42	1962.42	4.67	57.59
17	45.00	2278.85	0.02	17.66	17	36.50	1998.92	0.25	57.84
18	269.90	2548.75	2.08	19.74	18	113.75	2112.67	0.5	58.34
19	138.02	2686.76	6.5	26.24	19	95.67	2208.33	0.83	59.17

20	14.67	2701.44	0.32	26.56	20	58.00	2266.33	4	63.17
21	252.00	2953.44	1.5	28.06	21	168.50	2434.83	2	65.17
22	369.50	3322.94	17.5	45.56	22	134.00	2568.83	0.25	65.42
23	203.00	3525.94	1.42	46.98	23	198.33	2767.17	0.08	65.5
24	415.08	3941.02	1	47.98	24	24.85	2792.02	8.5	74
25	274.52	4215.54	1.32	49.3	25	244.32	3036.34	0.25	74.25
26	38.92	4254.45	0.5	49.8	26	17.42	3053.75	3	77.25
27	31.77	4286.22	12.73	62.53	27	32.67	3086.43	2.09	79.34
28	95.25	4381.47	0.83	63.36	28	84.74	3171.17	0.33	79.67
29	87.67	4469.14	0.5	63.86	29	48.17	3219.33	0.33	80
30	114.77	4583.90	3.57	67.43	30	125.17	3344.50	2	82
31	73.67	4657.57	4.51	71.94	31	7.02	3351.52	0.82	82.82
32	18.50	4676.07	5.42	77.36	32	31.17	3382.68	1.83	84.65
33	14.08	4690.16	2.57	79.93	33	14.68	3397.36	312.73	397.38
34	45.92	4736.08	6.52	86.45	34	4.00	3401.36	0.58	397.96
35	23.98	4760.06	7.67	94.12	35	16.67	3418.03	156	553.96
36	1.00	4761.06	15.58	109.7	36	60.01	3478.04	1.5	555.46
37	54.25	4815.31	0.83	110.53	37	51.50	3529.54	24.76	580.22
38	22.42	4837.73	0.25	110.78	38	124.73	3654.27	0.25	580.47
39	67.75	4905.48	0.08	110.86	39	5.60	3659.87	0.66	581.13
40	63.75	4969.23	2.42	113.28	40	93.22	3753.09	17.02	598.15
41	3.00	4972.23	2.67	115.95	41	174.25	3927.34	1.33	599.48
42	30.00	5002.23	0.84	116.79	42	11.17	3938.50	0.08	599.56
43	12.75	5014.97	0.08	116.87	43	6.92	3945.42	1	600.56
44	3.17	5018.14	1.26	118.13	44	21.67	3967.09	14.33	614.89
45	36.24	5054.38	0.33	118.46	45	107.00	4074.09	0.67	615.56
46	80.67	5135.04	3.01	121.47	46	23.33	4097.42	0.25	615.81
47	14.66	5149.70	0.08	121.55	47	64.00	4161.42	1	616.81
48	55.84	5205.54	0.05	121.6	48	32.25	4193.67	0.25	617.06
49	48.00	5253.54	6.87	128.47	49	37.50	4231.17	0.17	617.23
50	26.17	5279.70	0.08	128.55	50	7.33	4238.50	2.01	619.24
51	38.00	5317.70	4	132.55	51	47.75	4286.26	0.25	619.49
52	6.75	5324.45	0.08	132.63	52	39.26	4325.51	4.15	623.64
53	22.58	5347.04	0.5	133.13	53	141.35	4466.86	8.65	632.29
54	39.33	5386.37	4.75	137.88	54	215.00	4681.86	0.83	633.12
55	10.75	5397.12	7.52	145.4	55	70.00	4751.86	0.08	633.2
56	2.48	5399.60	66	211.4	56	224.42	4976.28	0.08	633.28
57	98.08	5497.69	0.33	211.73	57	137.25	5113.53	1.42	634.7
58	109.08	5606.77	31.01	242.74	58	0.58	5114.11	2.5	637.2
59	56.49	5663.26	0.5	243.24	59	18.17	5132.28	0.33	637.53
60	76.50	5739.76	0.75	243.99	60	66.46	5198.73	0.04	637.57

61	39.75	5779.51	0.5	244.49	61	6.50	5205.23	1.08	638.65
62	47.50	5827.01	0.5	244.99	62	6.92	5212.15	0.5	639.15
63	74.83	5901.84	0.42	245.41	63	22.17	5234.32	0.5	639.65
64	21.75	5923.59	1	246.41	64	79.52	5313.83	2.98	642.63
65	47.51	5971.10	4	250.41	65	122.67	5436.50	5.83	648.46
66	38.93	6010.03	3.1	253.51	66	92.25	5528.75	0.17	648.63
-	-	-	-	-	67	47.58	5576.33	0.83	649.46
-	-	-	-	-	68	110.15	5686.48	3.35	652.81
-	-	-	-	-	69	12.68	5699.16	4.73	657.54
-	-	-	-	-	70	159.25	5858.41	0.5	658.04

Table 6.10 TBF, TTR, CTBF, and CTTR for each subsystem of BD21 and BD22

BD21					**BD22**				
Sl. NO	TBF, hr	CTBF, hr	TTR, hr	CTTR, hr	Sl. NO	TBF, hr	CTBF, hr	TTR, hr	CTTR, hr
1	0.00	0.00	1.75	1.75	1	0.00	0.00	25.17	25.17
2	46.75	46.75	88.5	90.25	2	50.00	50.00	1.25	26.42
3	1.25	48.00	13.24	103.49	3	18.42	68.42	1.83	28.25
4	25.52	73.52	10.98	114.47	4	41.92	110.33	3.08	31.33
5	134.00	207.52	7.5	121.97	5	16.00	126.33	6	37.33
6	15.50	223.02	11.5	133.47	6	533.00	659.33	5.51	42.84
7	17.50	240.52	8	141.47	7	2.88	662.21	3.47	46.31
8	211.33	451.86	7.68	149.15	8	5.64	667.85	6.01	52.32
9	144.66	596.52	39.83	188.98	9	30.67	698.52	3.83	56.15
10	39.17	635.68	0.5	189.48	10	91.50	790.03	10.51	66.66
11	238.35	874.03	9.57	199.05	11	84.98	875.01	2.01	68.67
12	3.95	877.98	0.49	199.54	12	35.49	910.50	4.85	73.52
13	158.97	1036.96	7.5	207.04	13	12.01	922.51	55.67	129.19
14	39.51	1076.47	5.1	212.14	14	5.63	928.15	0.67	129.86
15	57.39	1133.86	14.75	226.89	15	16.92	945.07	28.79	158.65
16	9.41	1143.28	0.33	227.22	16	40.96	986.03	9	167.65
17	4.00	1147.28	11.77	238.99	17	29.12	1015.14	1.01	168.66
18	590.98	1738.26	37.13	276.12	18	8.87	1024.01	2	170.66
19	28.62	1766.88	17.71	293.83	19	45.25	1069.26	34.25	204.91
20	34.04	1800.92	9.01	302.84	20	76.00	1145.26	7.5	212.41
21	38.24	1839.17	13.26	316.1	21	39.52	1184.78	9.99	222.4
22	80.90	1920.07	12.84	328.94	22	14.16	1198.94	14.25	236.65
23	18.01	1938.08	10.89	339.83	23	59.92	1258.86	17.67	254.32
24	42.10	1980.17	1.34	341.17	24	92.50	1351.36	60	314.32
25	8.42	1988.60	3.32	344.49	25	132.02	1483.37	21.48	335.8
26	4.66	1993.26	8.52	353.01	26	121.50	1604.87	34.25	370.05
27	5.25	1998.50	24	377.01	27	79.27	1684.14	5.75	375.8

28	14.49	2013.00	6	383.01	28	6.74	1690.87	16.84	392.64
29	14.75	2027.75	13.26	396.27	29	495.66	2186.53	4.51	397.15
30	15.99	2043.74	0.67	396.94	30	342.50	2529.03	19.88	417.03
31	192.42	2236.16	0.45	397.39	31	37.20	2566.23	0.42	417.45
32	7.21	2243.37	2.5	399.89	32	0.25	2566.48	1.00	418.45
33	41.58	2284.95	10.17	410.06	33	9.26	2575.74	0.33	418.78
34	159.33	2444.29	1.69	411.75	34	6.66	2582.39	3.5	422.28
35	106.97	2551.26	32.09	443.84	35	17.00	2599.39	2	424.28
36	315.91	2867.17	24.33	468.17	36	6.50	2605.89	0.58	424.86
37	59.42	2926.58	10.26	478.43	37	10.92	2616.81	4	428.86
38	78.26	3004.84	1.83	480.26	38	75.00	2691.81	23	451.86
39	50.91	3055.75	0.67	480.93	39	107.27	2799.08	0.17	452.03
40	106.33	3162.08	20.72	501.65	40	141.07	2940.14	0.67	452.7
41	53.28	3215.36	18.51	520.16	41	33.83	2973.98	0.33	453.03
42	27.16	3242.51	4.84	525.00	42	299.17	3273.15	1.5	454.53
43	125.51	3368.03	0.41	525.41	43	4.01	3277.16	1.83	456.36
44	53.82	3421.85	28.25	553.66	44	12.66	3289.81	16	472.36
45	9.00	3430.85	16	569.66	45	59.43	3349.24	10.07	482.43
46	7.50	3438.35	4.5	574.16	46	57.68	3406.92	0.41	482.84
47	7.75	3446.10	2.75	576.91	47	12.41	3419.33	6.33	489.17
48	39.83	3485.93	42.25	619.16	48	138.18	3557.51	0.16	489.33
49	151.76	3637.69	1.66	620.82	49	47.33	3604.84	8.24	497.57
50	132.33	3770.02	29.67	650.49	50	18.09	3622.94	86.5	584.07
51	12.33	3782.36	4.54	655.03	51	7.91	3630.85	33.75	617.82
52	48.79	3831.15	1.34	656.37	52	43.17	3674.01	10.67	628.49
53	20.49	3851.64	0.61	656.98	53	65.18	3739.19	0.84	629.33
54	28.56	3880.19	5.33	662.31	54	114.17	3853.36	3.47	632.8
55	155.52	4035.71	13.32	675.63	55	2.01	3855.37	0.83	633.63
56	37.67	4073.38	5.13	680.76	56	3.17	3858.55	1.25	634.88
57	16.03	4089.41	2	682.76	57	240.75	4099.30	17.5	652.38
58	1.50	4090.91	5.58	688.34	58	6.01	4105.31	9.24	661.62
59	15.25	4106.16	125	813.34	59	31.25	4136.56	20.25	681.87
60	0.02	4106.18	115.18	928.52	60	30.75	4167.31	3.42	685.29
61	5.80	4111.98	3.5	932.02	61	1.58	4168.89	8.78	694.07
62	28.00	4139.98	0.33	932.35	62	6.73	4175.62	8.75	702.82
63	19.92	4159.89	1	933.35	63	7.75	4183.37	9.02	711.84
64	41.08	4200.98	41.17	974.52	64	17.31	4200.68	14.17	726.01
65	9.74	4210.72	5.25	979.77	65	76.00	4276.68	51.01	777.02
66	56.01	4266.73	8.32	988.09	66	23.24	4299.91	34.46	811.48
67	41.83	4308.56	0.17	988.26	67	19.30	4319.21	25.68	837.16
68	39.76	4348.32	17.17	1005.4	68	7.56	4326.77	89.08	926.24

69	23.58	4371.90	5.96	1011.3	69	3.42	4330.19	6.26	932.5
70	17.70	4389.60	7.33	1018.7	70	73.50	4403.69	8.49	940.99
71	1.17	4390.77	8.86	1027.5	71	67.00	4470.69	60.01	1001
72	56.14	4446.91	5.92	1033.5	72	0.99	4471.68	1	1002
73	41.08	4487.99	2	1035.5	73	37.83	4509.52	96.46	1098.4
74	41.00	4528.99	7.83	1043.3	74	1.72	4511.23	2.99	1101.4
75	62.43	4591.42	3.62	1046.9	75	44.50	4555.73	2.01	1103.4
76	1.12	4592.53	2.25	1049.2	76	66.51	4622.23	16.83	1120.2
77	0.25	4592.78	19.34	1068.5	77	90.15	4712.39	5.87	1126.1
78	2.16	4594.94	24.34	1092.8	78	4.14	4716.52	8.95	1135.1
79	9.66	4604.60	46.94	1139.8	79	4.97	4721.49	38.41	1173.5
80	11.55	4616.16	26.33	1166.1	80	10.26	4731.75	5.32	1178.8
81	2.17	4618.33	0.83	1166.9	81	1.08	4732.84	16.17	1195.0
82	7.00	4625.33	15.67	1182.6	82	1.08	4733.92	4.76	1199.7
83	41.50	4666.83	35.77	1218.4	83	1.98	4735.90	10.5	1210.2
84	61.73	4728.56	1.83	1220.2	84	2.00	4737.90	10.42	1220.6
85	18.68	4747.24	50.98	1271.2	85	8.08	4745.98	2.22	1222.9
86	31.00	4778.24	7.25	1278.4	86	69.28	4815.27	40.5	1263.4
87	17.75	4795.99	55.18	1333.6	87	82.01	4897.28	14.14	1277.5
88	13.82	4809.81	1.75	1335.4	88	8.60	4905.88	15.17	1292.7
89	30.75	4840.56	0.75	1336.1	89	33.83	4939.71	0.5	1293.2
90	73.75	4914.31	16.5	1352.6	90	3.08	4942.79	10.6	1303.8
91	125.00	5039.31	16.45	1369.1	91	17.57	4960.37	7.5	1311.3
-	-	-	-	-	92	8.50	4968.87	16.76	1328.0
-	-	-	-	-	93	37.41	5006.28	3.33	1331.4
-	-	-	-	-	94	24.00	5030.28	4.02	1335.4
-	-	-	-	-	95	0.73	5031.01	10.42	1345.8
-	-	-	-	-	96	7.08	5038.09	6.67	1352.5
-	-	-	-	-	97	27.83	5065.93	109.2	1461.7

Table 6.11 TBF, TTR, CTBF, and CTTR for each subsystem of BD23 and KD24

BD23					**KD24**				
Sl. NO	TBF, hr	CTBF, hr	TTR, hr	CTTR, hr	Sl. NO	TBF, hr	CTBF, hr	TTR, hr	CTTR, hr
1	0.00	0.00	80.99	80.99	1	0	0	5.58	5.58
2	144.00	144.00	0.5	81.49	2	34.92	34.92	4.5	10.08
3	181.50	325.50	7.33	88.82	3	269.50	304.42	0.5	10.58
4	20.17	345.67	0.33	89.15	4	136.00	440.42	2.5	13.08
5	16.17	361.83	28	117.15	5	173.50	613.92	0.5	13.58
6	28.02	389.85	1.99	119.14	6	77.00	690.92	0.75	14.33
7	52.50	442.35	0.08	119.22	7	54.75	745.67	1	15.33
8	186.42	628.76	2.5	121.72	8	130.67	876.33	0.58	15.91

9	113.50	742.26	0.5	122.22	9	4.25	880.58	17.5	33.41
10	195.50	937.76	20.95	143.17	10	102.50	983.08	2.5	35.91
11	38.05	975.82	9	152.17	11	66.67	1049.7	64.16	100.07
12	98.50	1074.31	2.01	154.18	12	62.67	1112.4	0.67	100.74
13	47.99	1122.30	4	158.18	13	74.83	1187.2	1	101.74
14	73.01	1195.31	7.24	165.42	14	447.75	1635	0.75	102.49
15	17.08	1212.39	6.17	171.59	15	201.50	1836.5	13.5	115.99
16	42.42	1254.81	6.58	178.17	16	108.00	1944.5	105.83	221.82
17	128.00	1382.81	5	183.17	17	151.00	2095.5	3.17	224.99
18	260.66	1643.48	0.33	183.5	18	118.50	2214.0	6.5	231.49
19	138.50	1781.98	10.5	194	19	67.83	2281.8	3.42	234.91
20	268.16	2050.14	12.33	206.33	20	283.75	2565.5	0.17	235.08
21	87.00	2137.14	11	217.33	21	65.17	2630.7	1	236.08
22	295.75	2432.89	20	237.33	22	231.50	2862.2	0.67	236.75
23	169.76	2602.65	1.49	238.82	23	17.67	2879.9	4.33	241.08
24	116.00	2718.64	42	280.82	24	24.67	2904.5	7.58	248.66
25	177.50	2896.14	2.5	283.32	25	16.60	2921.1	0.33	248.99
26	78.51	2974.66	0.17	283.49	26	47.83	2969.0	0.75	249.74
27	261.82	3236.48	0.33	283.82	27	1.58	2970.6	0.41	250.15
28	96.67	3333.14	11	294.82	28	25.26	2995.8	40.75	290.9
29	62.67	3395.82	0.24	295.06	29	43.75	3039.6	3.42	294.32
30	22.92	3418.73	0.17	295.23	30	123.57	3163.1	2	296.32
31	8.00	3426.73	4.03	299.26	31	13.00	3176.1	3	299.32
32	1.47	3428.20	18.25	317.51	32	14.50	3190.6	0.26	299.58
33	109.75	3537.94	2.5	320.01	33	78.23	3268.9	0.83	300.41
34	86.85	3624.79	0.16	320.17	34	71.17	3340.0	1	301.41
35	112.00	3736.78	3.5	323.67	35	8.42	3348.5	0.08	301.49
36	11.50	3748.28	16.75	340.42	36	10.75	3359.2	8.25	309.74
37	100.75	3849.03	27.35	367.77	37	38.25	3397.5	0.42	310.16
38	30.89	3879.92	15.6	383.37	38	14.17	3411.6	0.67	310.83
39	5.34	3885.26	43.5	426.87	39	12.00	3423.6	0.75	311.58
40	39.84	3925.10	21.01	447.88	40	5.25	3428.9	0.5	312.08
41	7.15	3932.25	3.83	451.71	41	70.00	3498.9	9.5	321.58
42	4.08	3936.33	5.67	457.38	42	6.33	3505.2	18.92	340.5
43	1.25	3937.58	4.15	461.53	43	34.25	3539.5	1.35	341.85
44	2.36	3939.94	4.83	466.36	44	102.67	3642.1	51.98	393.83
45	3.00	3942.94	19.17	485.53	45	21.00	3663.1	2.5	396.33
46	4.50	3947.44	62.5	548.03	46	117.50	3780.6	1	397.33
47	1.00	3948.44	382.28	930.31	47	25.00	3805.6	1	398.33
48	39.21	3987.65	18.52	948.83	48	110.03	3915.7	0.47	398.8
49	19.40	4007.05	0.59	949.42	49	211.50	4127.2	1	399.8

50	68.50	4075.55	0.5	949.92	50	51.50	4178.7	6.5	406.3
51	15.25	4090.80	8	957.92	51	208.00	4386.7	0.5	406.8
52	9.08	4099.88	0.5	958.42	52	72.01	4458.7	3.5	410.3
53	19.17	4119.05	1.5	959.92	53	67.49	4526.2	10.33	420.63
54	39.52	4158.57	4.98	964.9	54	21.18	4547.4	0.02	420.65
55	21.50	4180.07	14.5	979.4	55	232.47	4779.8	5.33	425.98
56	3.01	4183.08	74.35	1053.7	56	42.67	4822.5	4	429.98
57	28.13	4211.21	1	1054.7	57	27.52	4850.0	1.98	431.96
58	0.75	4211.96	4.42	1059.1	58	4.75	4854.8	2.25	434.21
59	1.76	4213.72	18.57	1077.7	-	-	-	-	-
60	54.76	4268.48	16.91	1094.6	-	-	-	-	-
61	23.84	4292.31	4.31	1098.9	-	-	-	-	-
62	2.19	4294.50	468.03	1566.9	-	-	-	-	-
63	26.48	4320.97	4	1570.9	-	-	-	-	-
64	1.84	4322.81	0.58	1571.5	-	-	-	-	-
65	26.33	4349.14	17.34	1588.9	-	-	-	-	-
66	48.25	4397.38	6.42	1595.3	-	-	-	-	-
67	47.25	4444.63	0.83	1596.1	-	-	-	-	-
68	107.18	4551.82	8.48	1604.6	-	-	-	-	-
69	3.50	4555.32	0.67	1605.3	-	-	-	-	-
70	1.83	4557.15	0.67	1605.9	-	-	-	-	-
71	36.83	4593.98	3.5	1609.4	-	-	-	-	-
72	1.50	4595.48	15.92	1625.4	-	-	-	-	-
73	3.58	4599.07	15	1640.4	-	-	-	-	-
74	72.50	4671.57	16.77	1657.1	-	-	-	-	-
75	37.73	4709.30	0.5	1657.6	-	-	-	-	-
76	15.50	4724.80	1.02	1658.6	-	-	-	-	-

Table 6.12 TBF, TTR, CTBF, and CTTR for each subsystem of KD25 and KD26

KD25					**KD26**				
Sl. NO	TBF, hr	CTBF, hr	TTR, hr	CTTR, hr	Sl. NO	TBF, hr	CTBF, hr	TTR, hr	CTTR, hr
1	0.00	0.00	5.92	5.92	1	0.00	0.00	3.33	3.33
2	224.83	224.83	1.34	7.26	2	52.17	52.17	5.5	8.83
3	22.84	247.67	1.17	8.43	3	8.75	60.92	13.25	22.08
4	9.34	257.01	296.48	304.91	4	12.02	72.94	11.48	33.56
5	39.85	296.86	4.17	309.08	5	175.83	248.77	8.5	42.06
6	41.49	338.35	4.24	313.32	6	223.83	472.60	0.83	42.89
7	155.77	494.11	0.4	313.72	7	87.25	559.85	10.08	52.97
8	360.58	854.69	0.25	313.97	8	16.00	575.85	0.42	53.39
9	426.58	1281.28	0.42	314.39	9	99.99	675.84	0.01	53.4
10	67.75	1349.03	3.67	318.06	10	115.25	791.09	8.75	62.15

11	5.08	1354.11	12.75	330.81	11	26.75	817.84	0.42	62.57
12	104.50	1458.61	1	331.81	12	10.08	827.92	1.75	64.32
13	94.00	1552.61	0.33	332.14	13	36.50	864.42	0.33	64.65
14	66.17	1618.78	3.85	335.99	14	1278.9	2143.34	8.84	73.49
15	90.65	1709.43	37.17	373.16	15	113.69	2257.02	2.31	75.8
16	316.83	2026.26	4.42	377.58	16	131.16	2388.18	0.67	76.47
17	70.08	2096.34	1.5	379.08	17	7.34	2395.53	16.32	92.79
18	93.77	2190.11	0.5	379.58	18	10.17	2405.69	6	98.79
19	85.74	2275.85	0.58	380.16	19	39.50	2445.19	2	100.79
20	18.17	2294.01	0.58	380.74	20	11.00	2456.19	0.5	101.29
21	28.67	2322.68	1.17	381.91	21	210.31	2666.50	5.01	106.3
22	5.83	2328.51	5.27	387.18	22	360.18	3026.68	0.5	106.8
23	7.07	2335.58	0.42	387.6	23	2.67	3029.35	13.67	120.47
24	40.50	2376.08	2.42	390.02	24	11.18	3040.53	8.15	128.62
25	145.34	2521.42	0.5	390.52	25	10.83	3051.36	4	132.62
26	247.49	2768.91	12.33	402.85	26	20.00	3071.36	3.5	136.12
27	197.17	2966.08	0.33	403.18	27	89.00	3160.36	7.75	143.87
28	63.67	3029.75	0.5	403.68	28	88.75	3249.11	1.5	145.37
29	7.45	3037.19	0.50	404.18	29	17.03	3266.14	5.22	150.59
30	13.07	3050.26	3.48	407.66	30	60.08	3326.22	0.33	150.92
31	13.00	3063.26	0.75	408.41	31	5.33	3331.56	3	153.92
32	30.77	3094.03	2.82	411.23	32	115.75	3447.31	0.92	154.84
33	0.42	3094.44	1.25	412.48	33	170.17	3617.47	34.68	189.52
34	30.68	3125.13	0.15	412.63	34	191.48	3808.96	17	206.52
35	53.83	3178.96	1.33	413.96	35	258.33	4067.29	0.33	206.85
36	0.02	3178.98	0.82	414.78	36	61.83	4129.12	1	207.85
37	11.01	3189.98	11.16	425.94	37	35.50	4164.62	5.25	213.1
38	143.02	3333.00	0.74	426.68	38	103.58	4268.21	0.33	213.43
39	61.75	3394.74	2.5	429.18	39	6.35	4274.56	7.98	221.41
40	215.50	3610.24	0.5	429.68	40	267.00	4541.56	3.5	224.91
41	193.83	3804.08	17.92	447.6	41	49.50	4591.05	0.42	225.33
42	37.02	3841.09	0.25	447.85	42	124.83	4715.89	0.42	225.75
43	196.99	4038.08	1.5	449.35	43	106.83	4822.72	3	228.75
44	98.00	4136.08	2	451.35	44	143.34	4966.06	2.17	230.92
45	19.51	4155.59	3.25	454.6	45	129.66	5095.72	293.83	524.75
46	22.24	4177.84	10	464.6	46	72.25	5167.97	3.76	528.51
47	156.50	4334.34	0.75	465.35	47	31.49	5199.45	1.08	529.59
48	0.75	4335.09	4	469.35	48	6.92	5206.37	9.51	539.1
49	163.33	4498.42	0.33	469.68	49	47.58	5253.95	7.24	546.34
50	9.67	4508.09	5.49	475.17	50	0.33	5254.28	0.92	547.26
51	19.85	4527.94	1.16	476.33	51	17.58	5271.87	1	548.26

52	1.43	4529.37	0.43	476.76	52	36.50	5308.37	2.5	550.76
53	6.31	4535.68	5.5	482.26	53	21.50	5329.87	16.42	567.18
54	8.51	4544.19	0.99	483.25	54	2.08	5331.95	0.33	567.51
55	75.50	4619.69	0.5	483.75	55	13.17	5345.12	1.25	568.76
56	11.50	4631.19	78.25	562	56	22.27	5367.39	4.98	573.74
57	0.92	4632.11	5.25	567.25	57	3.50	5370.89	1	574.74
58	20.75	4652.86	3.25	570.5	58	64.50	5435.39	7.08	581.82
59	13.10	4665.95	4.24	574.74	-	-	-	-	-
60	6.25	4672.20	0.42	575.16	-	-	-	-	-
61	9.83	4682.03	2	577.16	-	-	-	-	-
62	5.75	4687.78	6.17	583.33	-	-	-	-	-
63	8.58	4696.37	38.5	621.83	-	-	-	-	-
64	17.58	4713.95	0.5	622.33	-	-	-	-	-
65	3.67	4717.62	20	642.33	-	-	-	-	-
66	72.51	4790.13	0.5	642.83	-	-	-	-	-
67	118.98	4909.11	2.5	645.33	-	-	-	-	-
68	14.33	4923.45	2.17	647.5	-	-	-	-	-
69	507.50	5430.95	0.02	647.52	-	-	-	-	-
70	81.98	5512.93	0.5	648.02	-	-	-	-	-
71	77.33	5590.26	6.17	654.19	-	-	-	-	-
72	39.50	5629.76	1.21	655.4	-	-	-	-	-
73	185.79	5815.55	0.75	656.15	-	-	-	-	-
74	110.75	5926.30	2.5	658.65	-	-	-	-	-

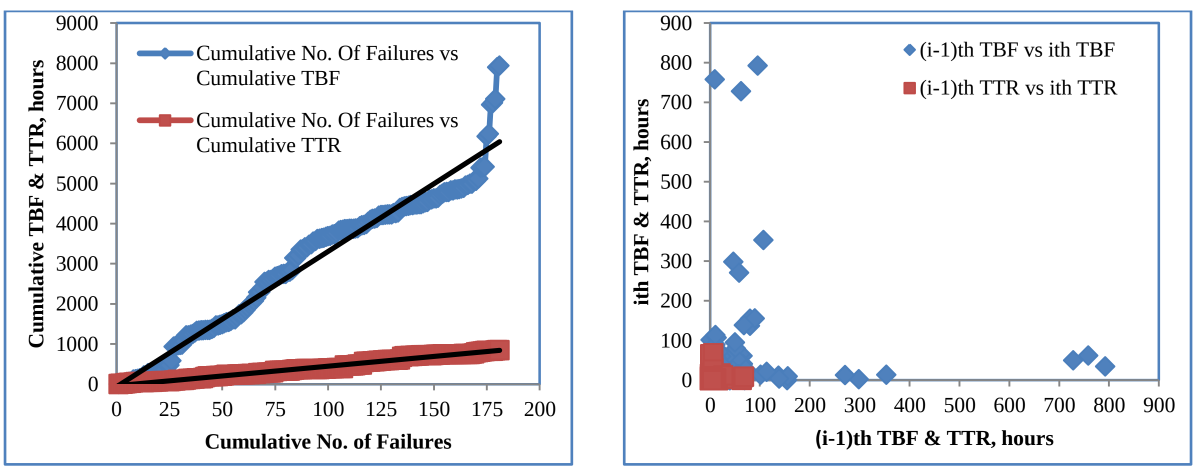
6.2 Serial Correlation and Trend Tests for TBF and TTR Data

6.2.1 Surface coal mine

The trend test for the current study was performed graphically. Analytical methods can be used to investigate data trends. Before fitting the data, it is necessary to check whether the data is trending if the system / component failure rate is increasing, decreasing, or constant. The trend of the failure data can be observed by plotting the cumulative time between failures and the number of failures. If there is a trend, the lines will be concave upwards, suggesting an improving system. If the line is concaving downwards, suggesting an improving system. If the line is linear, one can be sure that there is no trend in the data. The purpose of a series-related test is to examine the relationship between two variables. The scatter plots between the two variables (i^{th} TBFi and $(i-1)^{th}$ TBF) exhibits the correlation between the two variables.

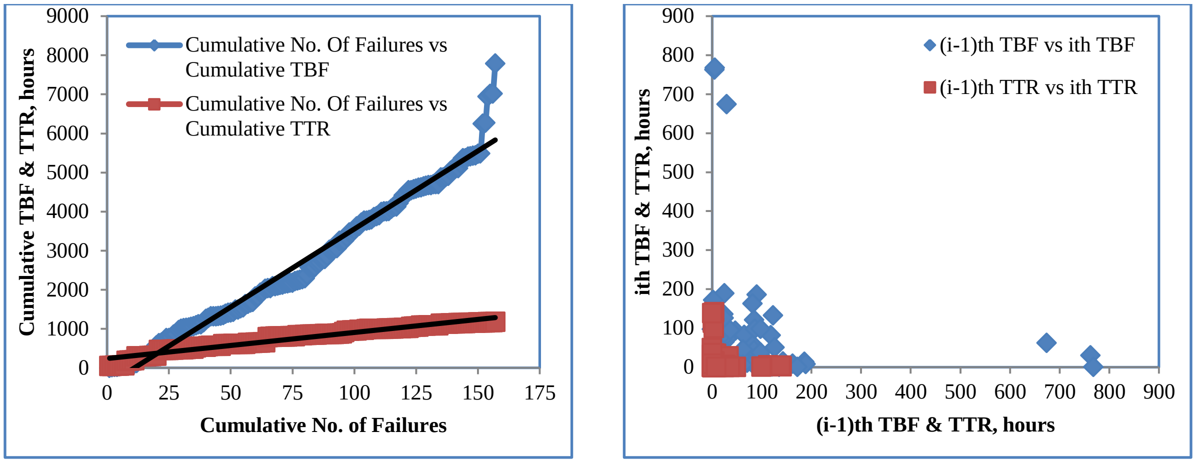
The trend and correlation test is performed between the schematic tests for TBF and TTR of system KS1 in the surface coal mine and shown in Figures 6.1 (a) and (b). The Figures 6.1 (a) and (b) is plotted between the cumulative time between failure and the number of failure for TBF and TTR of the KS1. It is observed that the line is linear and there is no trend in the data. Similarly, the scatter plot is drawn between two variables i.e., (i^{th} TBF and $(i\text{-}1)^{th}$ TBF). It is observed that the data is widely scattered and therefore, there no correlation between consecutive failure data. This is validating the assumptions of IID of TBF and TTR.

Similarly, the trend test and correlation test is done for other systems such as KS2, BD3, BD4, BD5, BD6, KD7, KD8, KD9 and KD10 and shown in Figure 6.2 (a) & (b), Figure 6.3 (a) & (b), Figure 6.4 (a) & (b), Figure 6.5 (a) & (b), Figure 6.6 (a) & (b), Figure 6.7 (a) & (b), Figure 6.8 (a) & (b), Figure 6.9 (a) & (b) and Figure 6.10 (a) & (b) respectively. From this analysis, it is observed that there was no trend between TBF and TTR with the number of failures in each case. The i^{th} TBF and $(i\text{-}1)^{th}$ TBF data is also found to follow the IID assumptions.



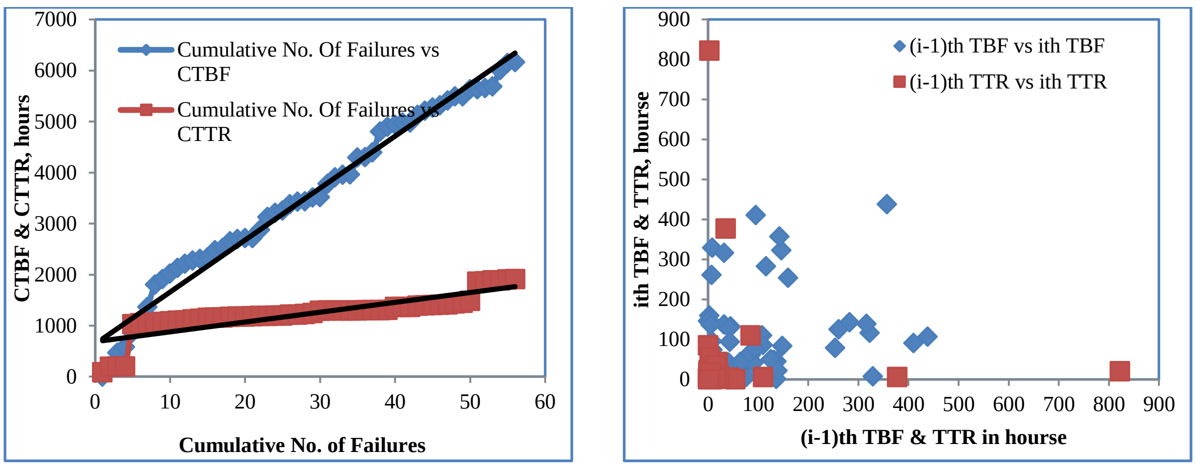
(a) (b)

Figure 6.1 System KS1 (a) Trend test for TBF & TTR (b) Correlation test for TBF & TTR



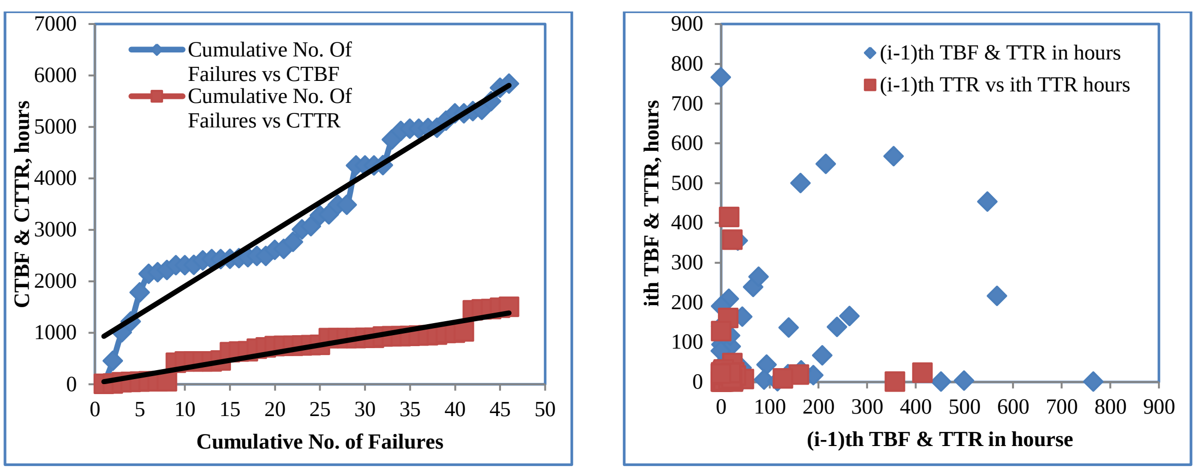
(a) (b)

Figure 6.2 System KS2 (a) Trend test for TBF & TTR (b) Correlation test for TBF & TTR



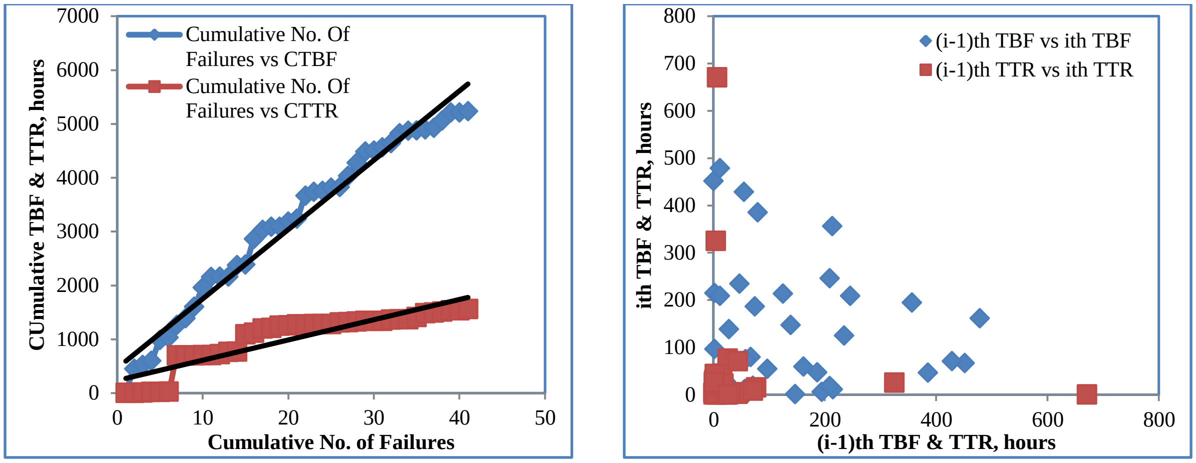
(a) (b)

Figure 6.3 System BD3 (a) Trend test for TBF & TTR (b) Correlation test for TBF & TTR



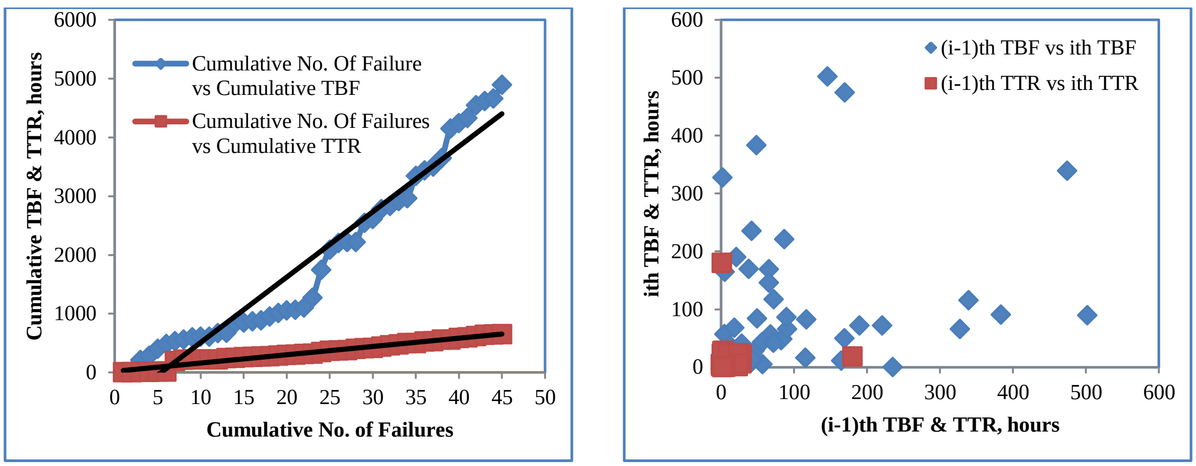
(a) (b)

Figure 6.4 System BD4 (a) Trend test for TBF & TTR (b) Correlation test for TBF & TTR



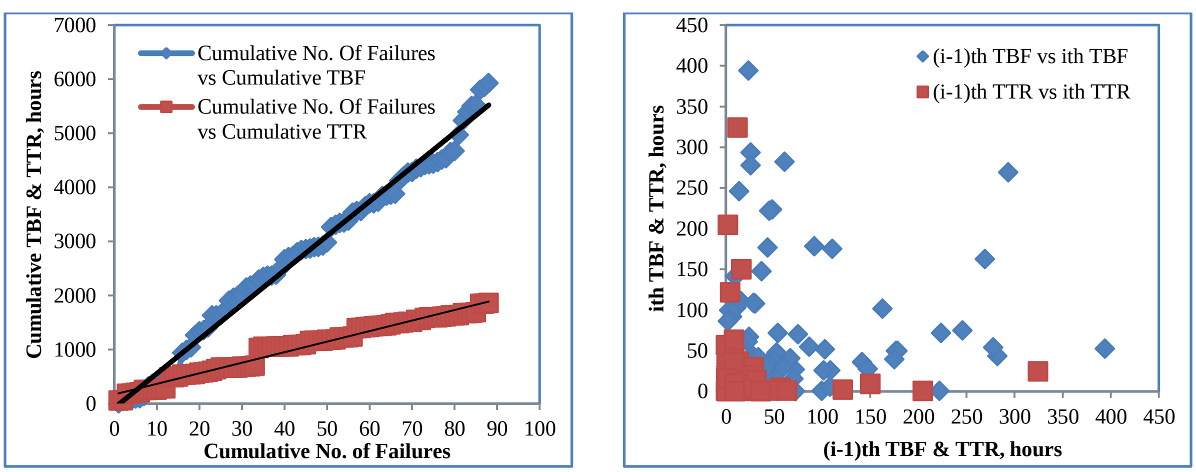
(a) (b)

Figure 6.5 System BD5 (a) Trend test for TBF & TTR (b) Correlation test for TBF & TTR



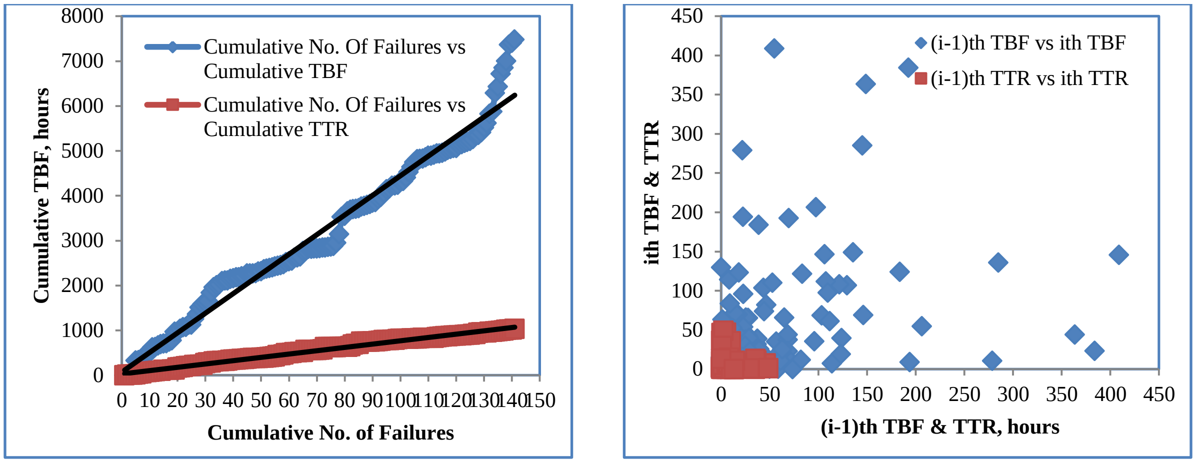
(a) (b)

Figure 6.6 System BD6 (a) Trend test for TBF & TTR (b) Correlation test for TBF & TTR



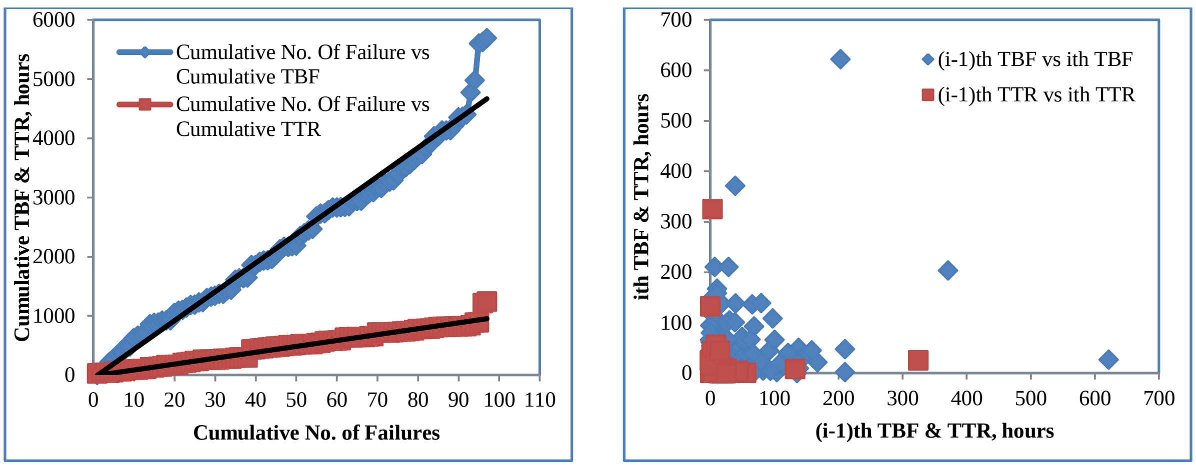
(a) (b)

Figure 6.7 System KD7 (a) Trend test for TBF & TTR (b) Correlation test for TBF & TTR



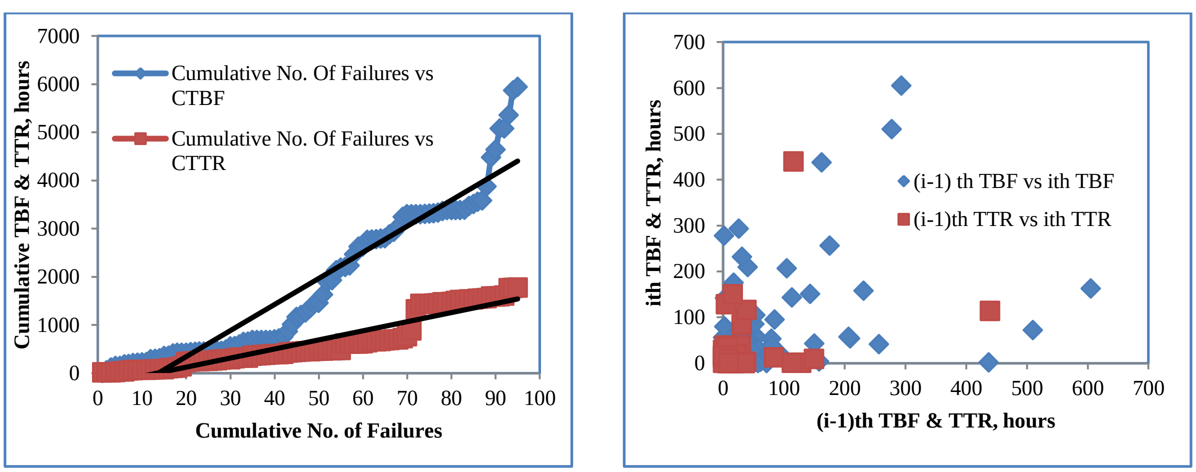
(a) (b)

Figure 6.8 System KD8 (a) Trend test for TBF & TTR (b) Correlation test for TBF & TTR



(a) (b)

Figure 6.9 System KD9 (a) Trend test for TBF & TTR (b) Correlation test for TBF & TTR



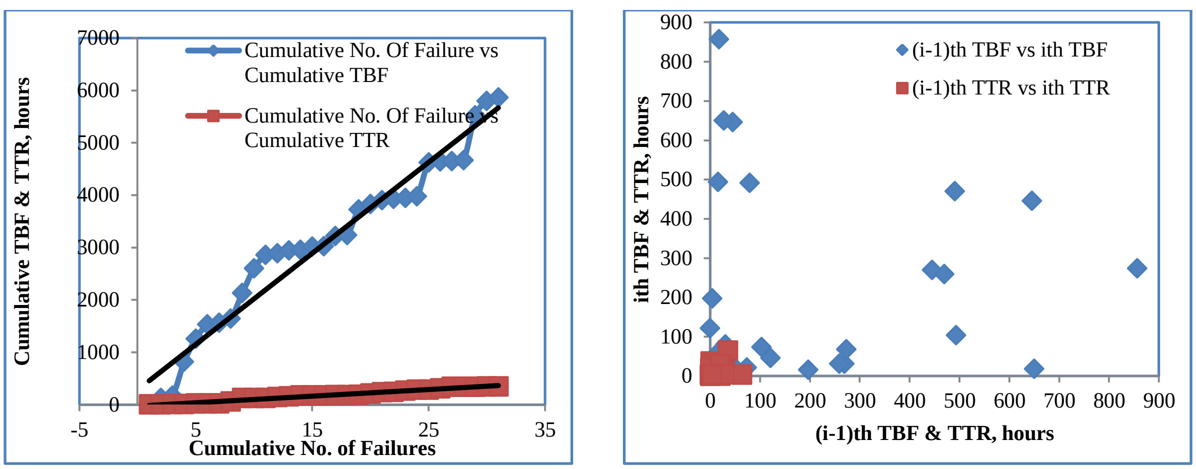
(a) (b)

Figure 6.10 System KD10 (a) Trend test for TBF & TTR (b) Correlation test for TBF & TTR

6.2.2 Surface iron ore mine

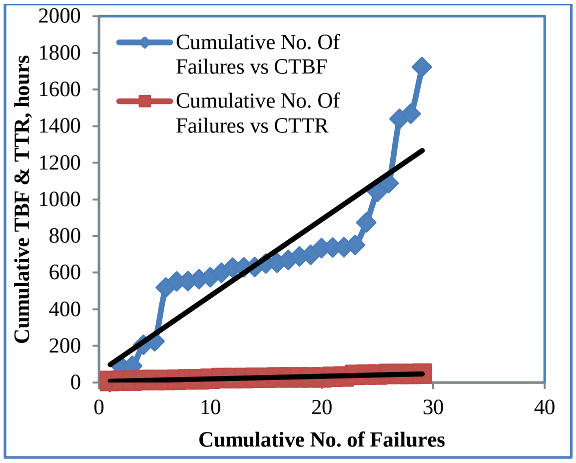
Also in surface iron ore mine, the trend and correlation tests are performed for TBF and TTR of shovels and dumpers. The trend and correlation test is performed between the schematic tests for TBF and TTR of system KS11 in surface iron ore mine and shown in Figure 6.11 (a) and (b). The Figure 6.11 (a) and (b) is plotted between cumulative time between failure and the number of failure of the KS11. It is observed that line is linear and no trend in the data. Similarly, the scatter plot is drawn between the two variables i.e., (i^{th} TBF) and $(i-1)^{th}$ TBF and it is observed that the data is much disperse. Therefore, there is no correlation between the data of two consecutive failures. This validates the IID assumptions of TBF and TTR.

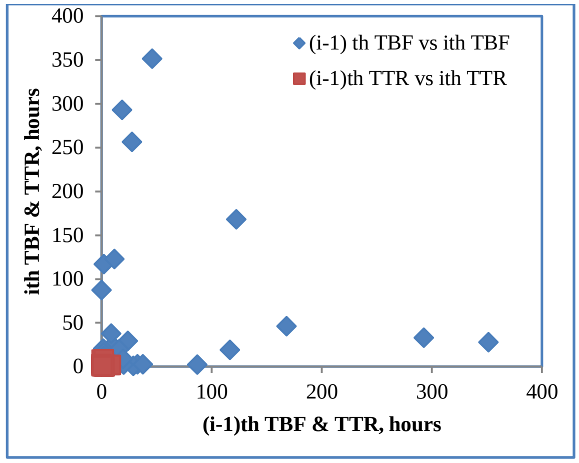
Similarly, the trend test and correlation test are conducted for other systems such as KS12, BD13, BD14, BD15, KD16, KD17 and KD18 are shown in Figure 6.12 (a) & (b), Figure 6.13 (a) & (b), Figure 6.14 (a) & (b), Figure 6.15 (a) & (b), Figure 6.16 (a) & (b), Figure 6.17 (a) & (b) and Figure 6.18 (a) & (b) respectively. From this analysis, it is observed that there is no trend between TBF and TTR with the number of failures in each case. The i^{th} TBF and $(i-1)^{th}$ TBF data were also found to follow the IID assumptions.



(a) (b)

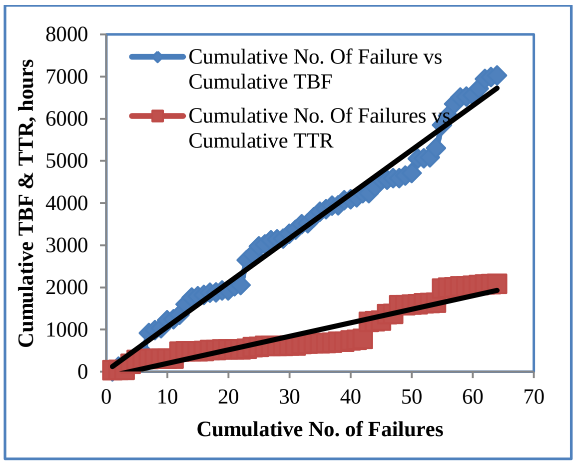
Figure 6.11 System KS11 (a) Trend test for TBF & TTR (b) Correlation test for TBF & TTR

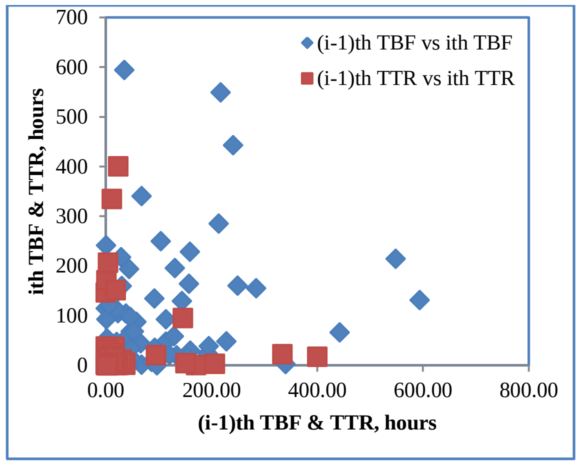




(a) (b)

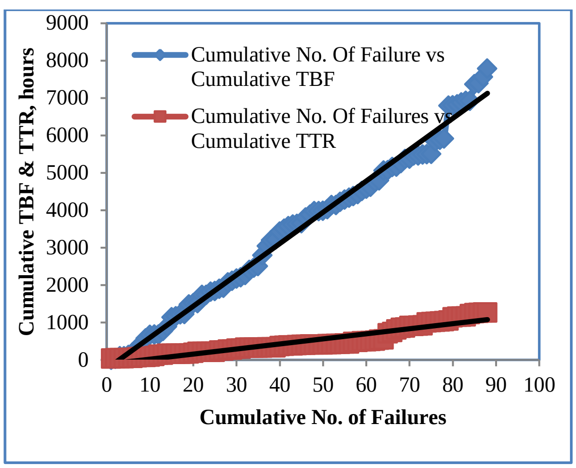
Figure 6.12 System KS12 (a) Trend test for TBF & TTR (b) Correlation test for TBF & TTR

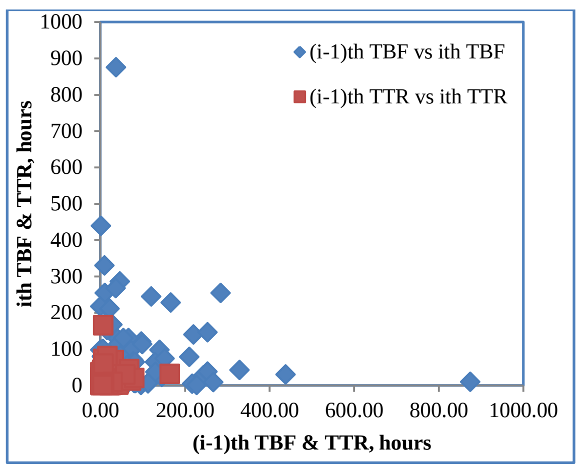




(a) (b)

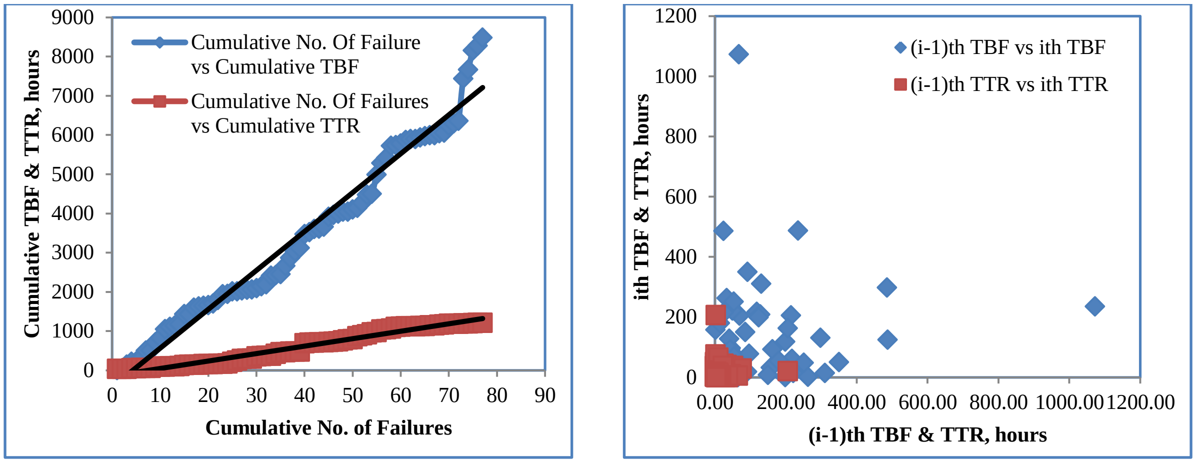
Figure 6.13 System BD13 (a) Trend test for TBF & TTR (b) Correlation test for TBF & TTR





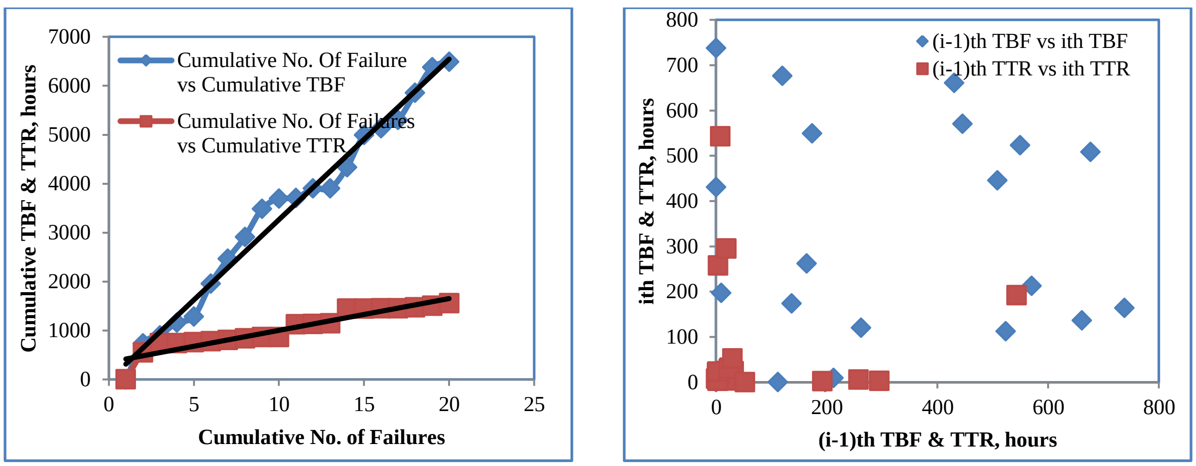
(a) (b)

Figure 6.14 System BD14 (a) Trend test for TBF & TTR (b) Correlation test for TBF & TTR



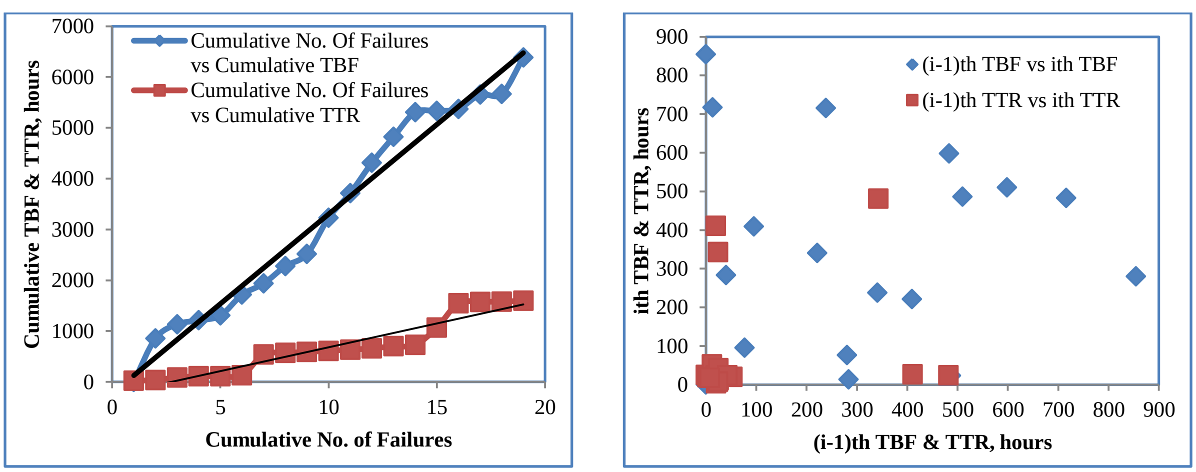
(a) (b)

Figure 6.15 System BD15 (a) Trend test for TBF & TTR (b) Correlation test for TBF & TTR



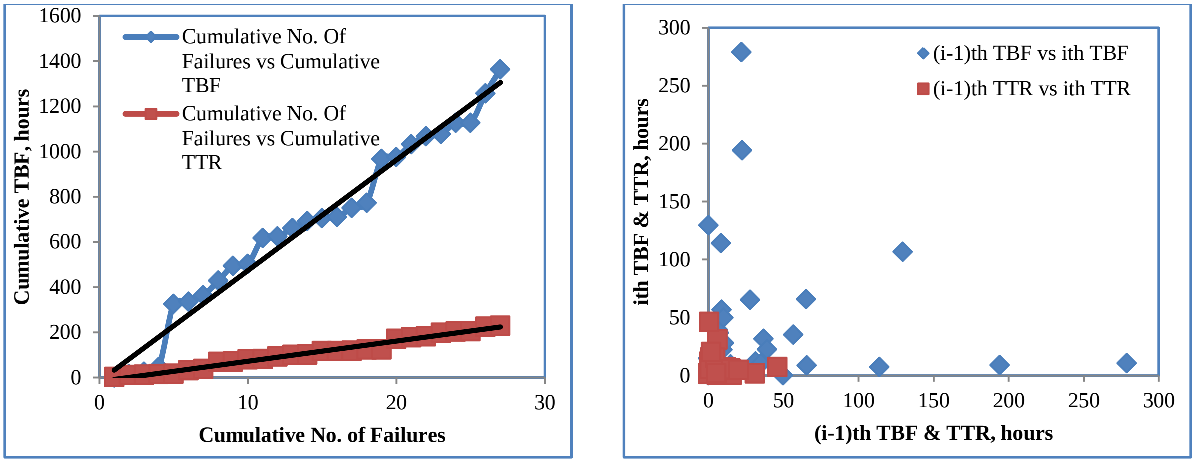
(a) (b)

Figure 6.16 System KD16 (a) Trend test for TBF & TTR (b) Correlation test for TBF & TTR



(a) (b)

Figure 6.17 System KD17 (a) Trend test for TBF & TTR (b) Correlation test for TBF & TTR



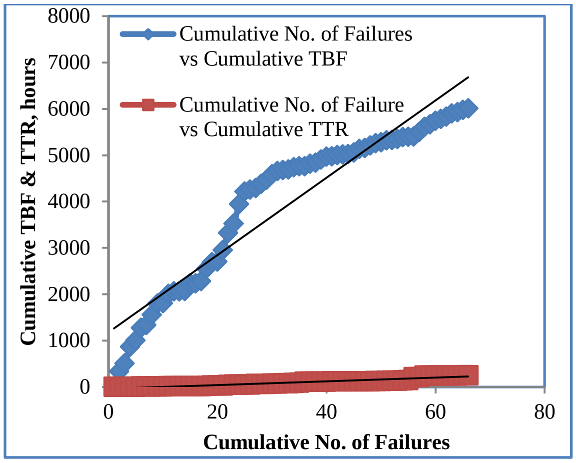
(a) (b)

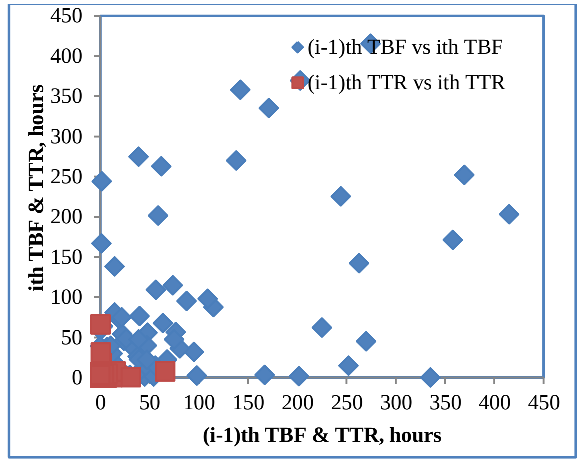
Figure 6.18 System KD18 (a) Trend test for TBF & TTR (b) Correlation test for TBF & TTR

6.2.3 Surface limestone mine

Similarly, in limestone mine, trend and correlation tests are performed for TBF and TTR of shovels and dumpers in surface limestone mine. The trend and correlation test is performed between the schematic tests for TBF and TTR of the KS19 and shown in Figure 6.19 (a) & (b). The Figure 6.19 (a) & (b) is plotted between cumulative time between failure and the number of failures of the KS19 observed that the line is linear. It is observed that that there is no trend in the data. Similarly, the scatter plot is drawn between the two variables i.e., (i^{th} TBFi and $(i-1)^{th}$ TBF) shows that the data is very dispersed and therefore there is no correlation between the data of two consecutive failures. This validates the IID assumptions of TBF and TTR.

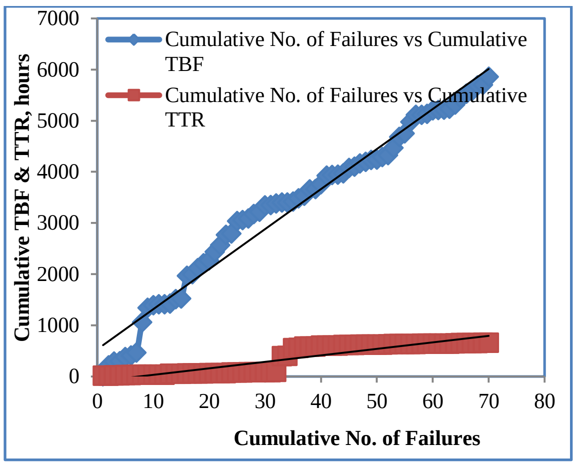
Similarly, the trend test and correlation test are conducted for other systems such as KS20, BD21, BD22, BD23, KD24, KD25 and KD26 are shown in Figure 6.20 (a) & (b), Figure 6.21 (a) & (b), Figure 6.22 (a) & (b), Figure 6.23 (a) & (b), Figure 6.24 (a) & (b), Figure 6.25 (a) & (b), Figure 6.26 (a) & (b) respectively. From this analysis, it is observed that there was no trend between TBF and TTR with the number of failures in each case. The i^{th} TBF and $(i-1)^{th}$ TBF data is also found to follow the IID assumptions.

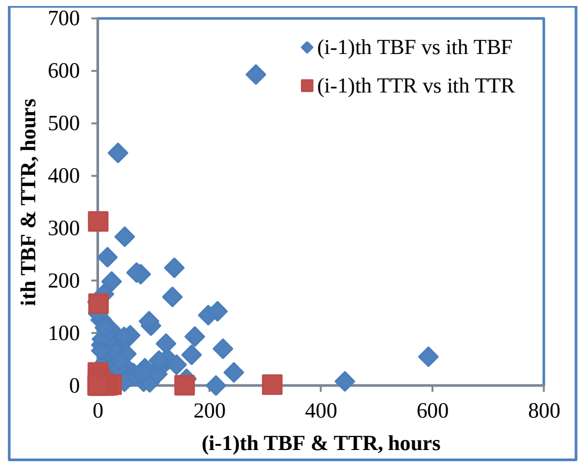




(a) (b)

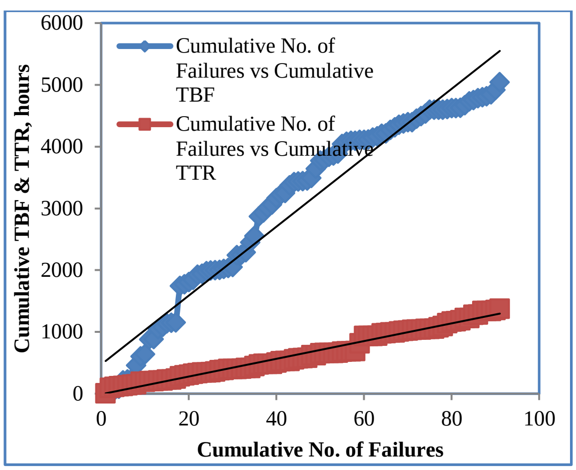
Figure 6.19 System KS19 (a) Trend test for TBF & TTR (b) Correlation test for TBF & TTR

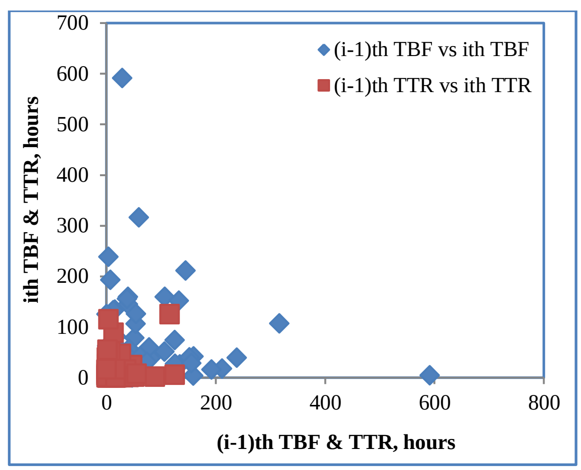




(a) (b)

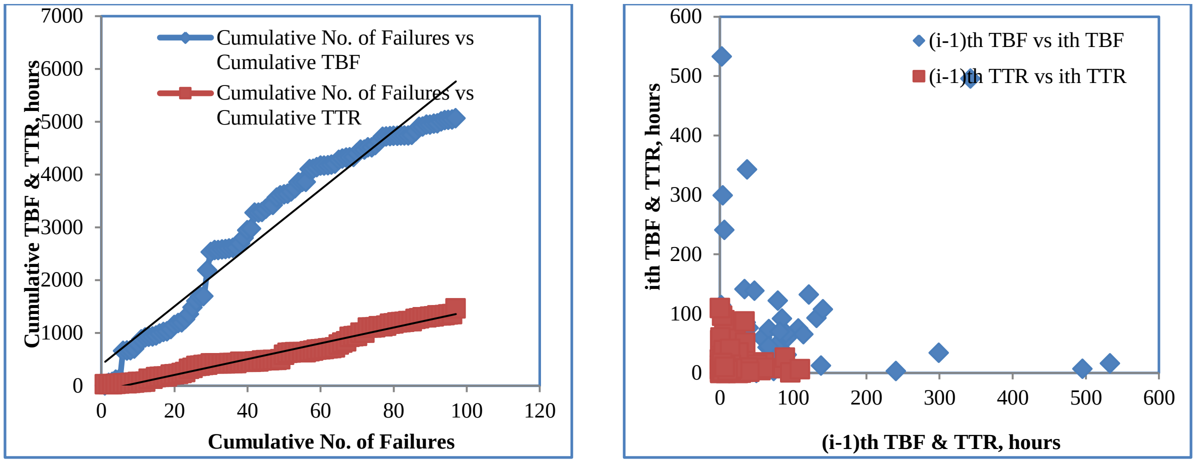
Figure 6.20 System KS20 (a) Trend test for TBF & TTR (b) Correlation test for TBF & TTR





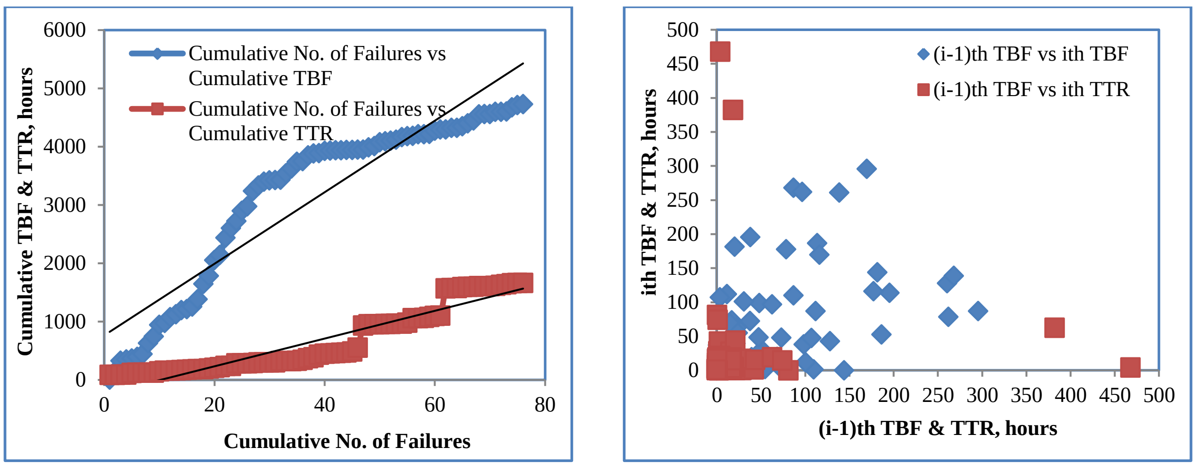
(a) (b)

Figure 6.21 System BD21 (a) Trend test for TBF & TTR (b) Correlation test for TBF & TTR



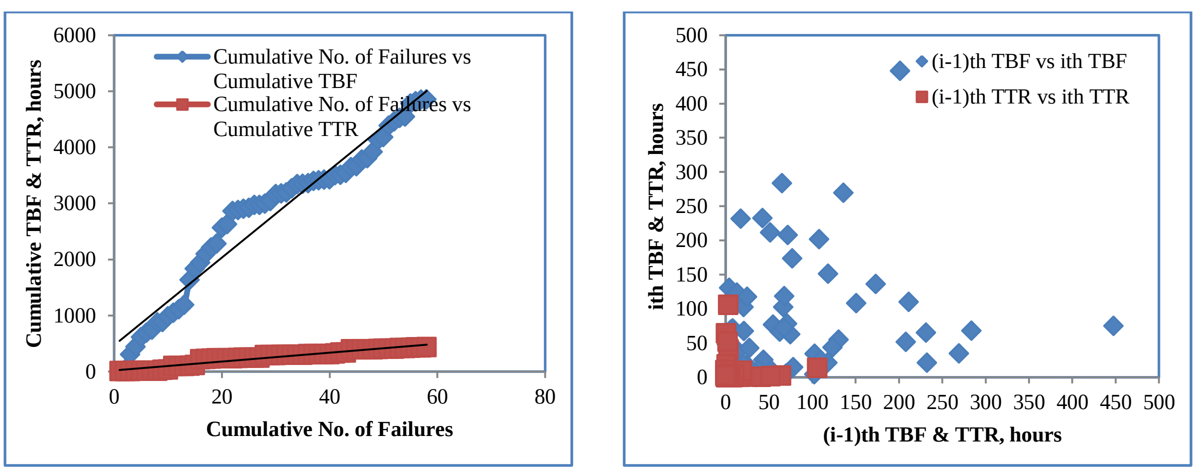
(a) (b)

Figure 6.22 System BD22 (a) Trend test for TBF & TTR (b) Correlation test for TBF & TTR



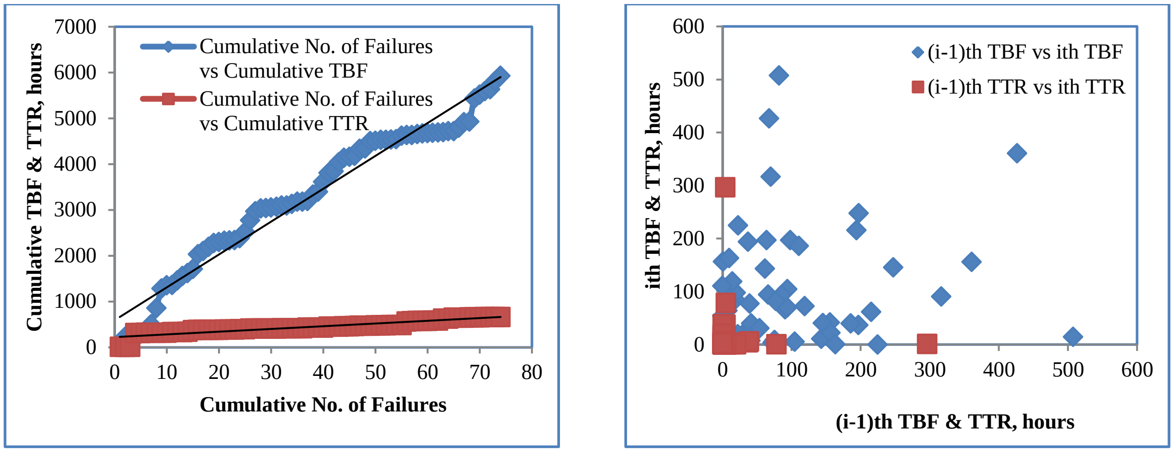
(a) (b)

Figure 6.23 System BD23 (a) Trend test for TBF & TTR (b) Correlation test for TBF & TTR



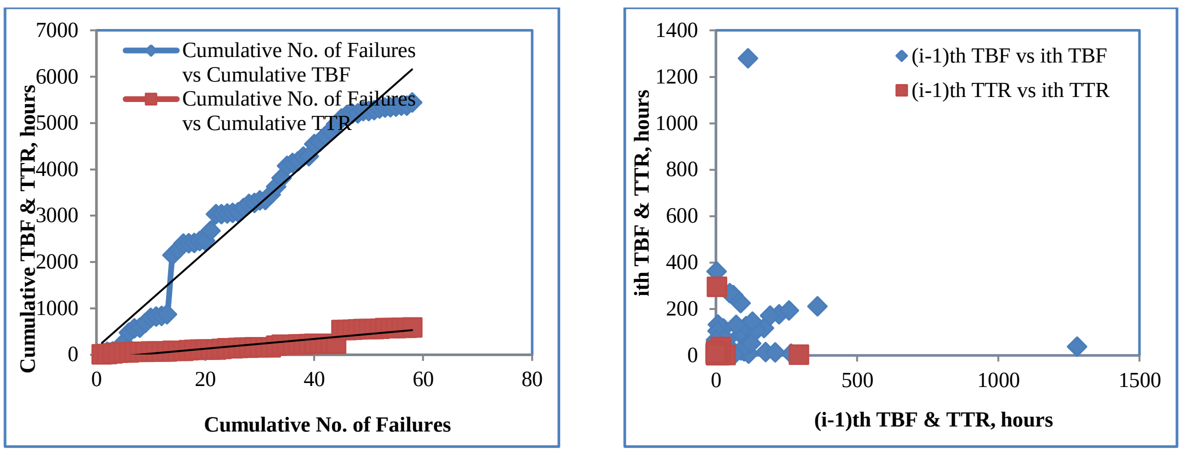
(a) (b)

Figure 6.24 System KD24 (a) Trend test for TBF & TTR (b) Correlation test for TBF & TTR



(a) (b)

Figure 6.25 System KD25 (a) Trend test for TBF & TTR (b) Correlation test for TBF & TTR



(a) (b)

Figure 6.26 System KD26 (a) Trend test for TBF & TTR (b) Correlation test for TBF & TTR

6.3 U-Statistic test for Shovel-Dumper system

The next step after collecting, sorting, and classifying the data is the validation of the IID characteristics of the TBF and TTR data for each shovel and dumper. This is done using the U-statistical test. The computed values of the U - statistic for the different system failures and repairs data are given in Table 6.13. It was found that Calculated U values are more than the values obtained by null hypothesis test. Therefore, the null hypothesis of TBF and TTR is not rejected at a 5% (0.05) level of significance for all the systems. It shows that the statistical test agrees with the results obtained in the trend test and the correlation test. In the serial correlation test, the points are randomly scattered in each case of shovel and dumper, which appear to be unrelated. The results obtained from the trend and serial correlation tests show that all systems and subsystem data sets do not have the presence of serial trends and correlations. Therefore, the premise that the data set is IID is complete for all systems.

Table 6.13 U-statistic test results of shovel and dumper for TBF & TTR respectively

Type of Surface Mine	Systems	Data Set	DOF	Calculated U	Rejection of Null Hypothesis at 5% level of significance (x)	Status
Surface Coal Mine	KS1	TBF	180	489.83	<212.304	Not rejected
		TTR	180	400.32	<212.304	Not rejected
	KS2	TBF	156	458.08	<186.146	Not rejected
		TTR	156	432.66	<186.146	Not rejected
	BD3	TBF	55	77.33	<73.311	Not rejected
		TTR	55	80.83	<73.311	Not rejected
	BD4	TBF	45	130.98	<61.656	Not rejected
		TTR	45	112	<61.656	Not rejected
	BD5	TBF	40	90.27	<55.758	Not rejected
		TTR	40	87.057	<55.758	Not rejected
	BD6	TBF	44	113.35	<61.656	Not rejected
		TTR	44	96.67	<61.656	Not rejected
	KD7	TBF	87	194.32	<109.773	Not rejected
		TTR	87	137.21	<109.773	Not rejected
	KD8	TBF	140	315.54	<168.613	Not rejected
		TTR	140	262.32	<168.613	Not rejected
	KD9	TBF	96	218.01	<122.108	Not rejected
		TTR	96	242.07	<122.108	Not rejected
	KD10	TBF	94	308.49	<118.752	Not rejected
		TTR	94	289.87	<118.752	Not rejected
Surface Iron Ore Mine	KS11	TBF	30	51.05	<43.773	Not rejected
		TTR	30	78.08	<43.773	Not rejected
	KS12	TBF	28	59.31	<41.337	Not rejected
		TTR	28	41.31	<41.337	Not rejected
	BD13	TBF	90	122.65	<113.145	Not rejected
		TTR	90	142.64	<113.145	Not rejected
	BD14	TBF	124	200.58	<150.989	Not rejected
		TTR	124	228.74	<150.989	Not rejected
	BD15	TBF	120	185.05	<146.567	Not rejected
		TTR	120	175.83	<146.567	Not rejected
	KD16	TBF	34	28.87	<19.806	Not rejected
		TTR	34	26.06	<19.806	Not rejected
	KD17	TBF	41	28.27	<25.215	Not rejected
		TTR	41	53.17	<25.215	Not rejected
	KD18	TBF	46	139.59	<62.830	Not rejected
		TTR	46	62.76	<62.830	Not rejected

Surface Limestone Mine	KS19	TBF	65	139.13	<84.821	Not rejected
		TTR	65	226.25	<84.821	Not rejected
	KS20	TBF	69	104.7	<89.391	Not rejected
		TTR	69	177.47	<89.391	Not rejected
	BD21	TBF	90	138.04	<113.145	Not rejected
		TTR	90	183.78	<113.145	Not rejected
	BD22	TBF	96	141.85	<119.871	Not rejected
		TTR	96	234.28	<119.871	Not rejected
	BD23	TBF	75	182.08	<96.217	Not rejected
		TTR	75	198.41	<96.217	Not rejected
	KD24	TBF	57	86.26	<75.624	Not rejected
		TTR	57	109.11	<75.624	Not rejected
	KD25	TBF	73	113.67	<93.945	Not rejected
		TTR	73	103.51	<93.945	Not rejected
	KD26	TBF	57	97.55	<75.624	Not rejected
		TTR	57	160.3	<75.624	Not rejected

6.4 Kolmogorov – Smirnov (K-S) Test for Shovel-Dumper system

The next step in the proposed work is to analyze the best-fit distribution functions for TBF data of shovel and dumper. The best fit analysis is performed using K-S test. The principle behind the goodness-of-fit test is to how far the chosen distribution is from the actual data set or in other words how well the chosen distribution represents the observed distribution. Four common probability distribution functions (i.e., 3-Weibull parameters, 2-Weibull parameters, 1-Weibull parameter, and 2-Eexponential parameters) were examined for modeling the failure data of each system, such as shovel and dumper. These four distributions are known to be suitable for modeling failures of mechanical systems and to have different characteristics to cover different types of data. To determine the best-fitted distribution for the datasets, the modified K-S goodness-of-fit tests have been used. The modified K-S tests and the estimation of parameters of the failure rate under maximum likelihood estimation (MLE) are determined using the Isograph Reliability Workbench (RWB) software. The results of the modified K-S tests for the four distributions and the estimated parameters of the best-fitted distribution function of the shovel and dumper for TBF and TTR data are listed in Table 6.14.

Table 6.14 Best fit distribution of shovel and dumper for their TBF

Type of Surface Mine	Systems	K-S test (goodness of fit)				Best Fit	Parameters		
		Exponential	Weibull 1P	Weibull 2P	Weibull 3P		η	β	γ
Surface Coal Mine	**KS1**	0.1298	0.0481	0.0245	0.028	Weibull 2P	29.83	0.7139	0
	KS2	0.1137	0.0486	0.0358	0.0263	Weibull 2P	37.21	0.7318	0
	BD3	0.0314	0.0415	0.0402	0.0335	Weibull 3P	115.7	1.018	-3.967
	BD4	0.145	0.146	0.0269	0.0308	Weibull 3P	83.12	0.5357	-0.2365
	BD5	0.063	0.0847	0.0367	0.0302	Weibull 3P	127.7	0.8916	-4.788
	BD6	0.0445	0.032	0.03	0.035	Weibull 3P	105.7	0.9341	-1.588
	KD7	0.0532	0.0336	0.0344	0.0161	Weibull 2P	62.61	0.7858	0
	KD8	0.0675	0.0341	0.0343	0.0208	Weibull 2P	47.68	0.8573	0
	KD9	0.0556	0.0502	0.0204	0.0253	Weibull 3P	51.88	0.7726	-0.0975
	KD10	0.1536	0.1143	0.0132	0.034	Weibull 3P	39.03	0.542	0
Surface Iron Ore Mine	**KS11**	0.1318	0.1026	0.0517	0.0411	Weibull 3P	143.6	0.5936	3.313
	KS12	0.1668	0.0847	0.0436	0.0396	Weibull 3P	37.62	0.5557	0.0506
	BD13	0.0361	0.0445	0.0212	0.0215	Weibull 3P	110.5	0.94	-3.44
	BD14	0.0435	0.0289	0.0251	0.0263	Weibull 2P	83.09	0.8311	0
	BD15	0.0686	0.0457	0.0289	0.0303	Weibull 2P	97.51	0.8	0
	KD16	0.0772	0.0682	0.0819	0.0614	Weibull 3P	570	2.08	-175.3
	KD17	0.0743	0.0079	0.0689	0.0402	Weibull 3P	568.4	1.899	-162.1
	KD18	0.0638	0.00687	0.0744	0.0285	Weibull 3P	386.7	1.61	-77.86
Surface Limestone Mine	**KS19**	0.0605	0.0534	0.0352	0.0285	Weibull 3P	85.12	0.84	-1.299
	KS20	0.0402	0.03601	0.0154	0.0154	Weibull 2P	78.43	0.82	0
	BD21	0.0719	0.0389	0.0376	0.0281	Weibull 3P	48.08	0.81	-0.219
	BD22	0.1051	0.0642	0.0239	0.0225	Weibull 2P	39.63	0.75	0
	BD23	0.0754	0.0817	0.0254	0.0274	Weibull 2P	53.49	0.71	0
	KD24	0.0262	0.0261	0.0191	0.0191	Weibull 2P	82.22	0.92	0
	KD25	0.0899	0.0853	0.0264	0.026	Weibull 2P	69.28	0.63	0
	KD26	0.0936	0.0669	0.0247	0.02471	Weibull 2P	74.13	0.74	0

The obtained bathtub curves (failure rate curves) of each shovel and dumper by K-S test are explained below briefly along with Weibull parameters (i.e., η, β and γ).

The failure rate curves (output of software) of shovel-dumper system are shown in Figures 6.27 to 6.36 for surface coal mine, Figures 6.37 to 6.44 for surface iron ore mine and Figures 6.45 to 6.52 for surface limestone mine. In the above Figures, X-axis is TBF and Y-Axis is failure rate.

It is observed that one of the failure mode of standard bathtub curve (same as shown in Figure 2.13) was obtained i.e., decreasing failure (failure mode-I: startup) or constant failure rate (failure mode-II: normal operation) or increasing failure rate (failure mode-III: end of the life). However, each shovel and dumper exhibiting different failure modes of bathtub curves and it is briefly explained in the following paragraph.

The nature of the failure trend in Figures 6.27 (KS1), 6.28 (KS2), 6.30 (BD4), 6.31 (BD5), 6.33 (KD7), 6.34 (KD8), 6.35 (KD9), 6.36 (KD10), 6.37 (KS11), 6.38 (KS12), 6.40 (BD14), 6.41 (BD15), 6.45 (KS19), 6.46 (KS20), 6.47 (BD21), 6.48 (BD22), 6.49 (BD23), 6.51 (KD25) and 6.52 (KD26) is decreasing and having β range is less than 1 (i.e., refer to Table 6.14 for β values). It can be inferred that above mentioned shovels and dumpers may have defects during manufacturing stage. i.e., higher probability for early failures upon first use. The elimination of early failures helps to obtain good reliability (Andres and Ljubisa 2015).

The nature of the failure trend in Figures 6.29 (BD3), 6.32 (BD6), 6.39 (BD13) and 6.50 (KD24) is constant failure rate and having β is equal to 1 (i.e., refer Table 6.14 for β values). It can be concluded that, BD3, BD6 and BD13 having arbitrary causes of failure. It indicates that early life has characterized by a higher rate of normal failures or failures which take less time for repair. These failures are called "infant mortality". The higher normal failure rates are often caused by defects in the production of faulty components that go undetected during production testing or are damaged during shipping, storage and installation work (Andres and Ljubisa 2015).

Similarly, the nature of the failure trend is in Figure 6.42 (KD16), 6.43 (KD17) and 6.44 (KD18) is increasing failure rate and having β is greater than 1 (i.e., refer Table 6.14 for β values). It can be stated that, KD16, KD17 and KD18 having probability for failure increases due to expiration of design lifetime (Andres and Ljubisa 2015).

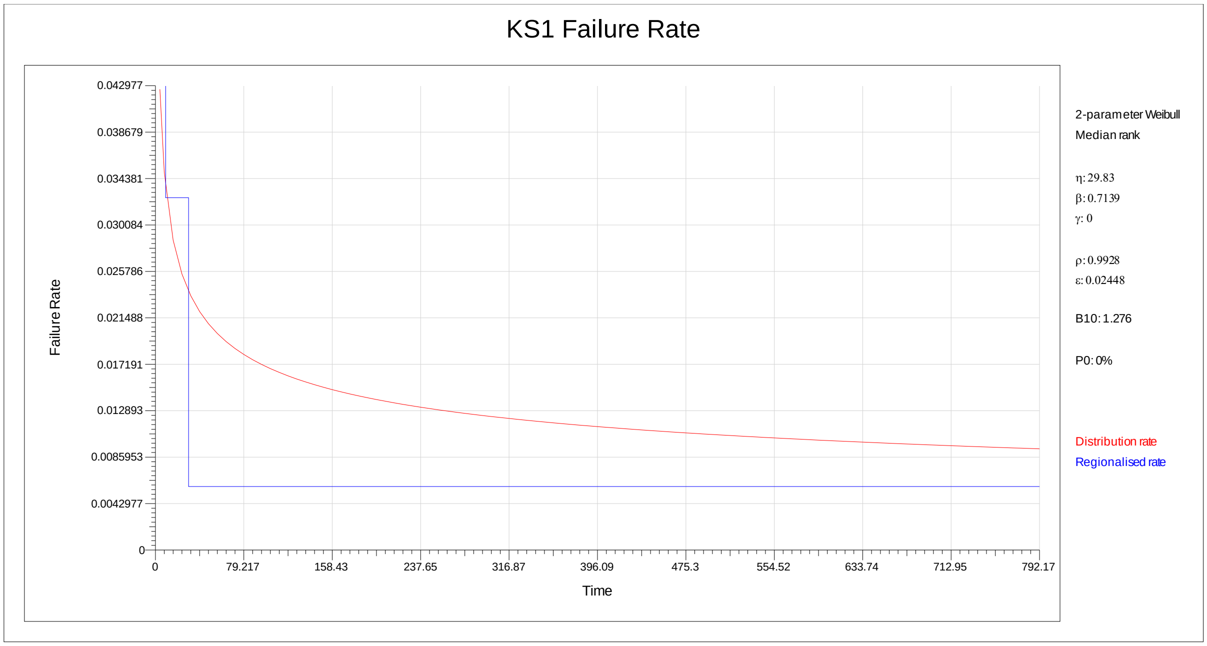


Figure 6.27 Failure rate of KS1for β=0.7139

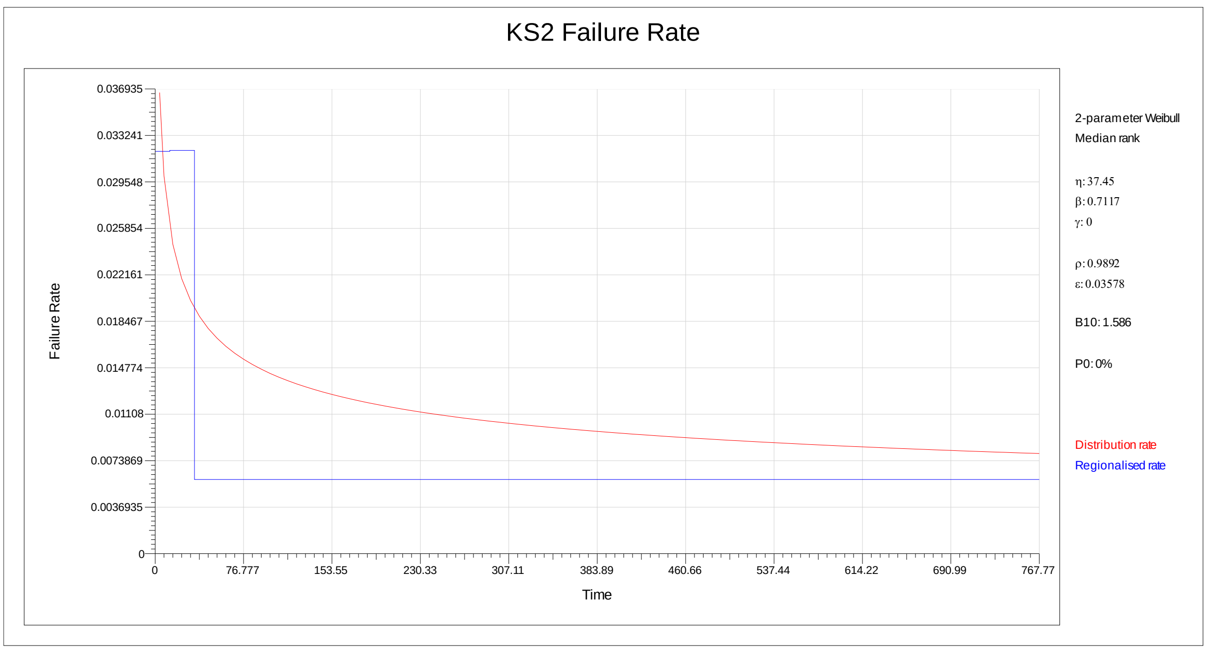


Figure 6.28 Failure rate of KS2 for β=0.7117

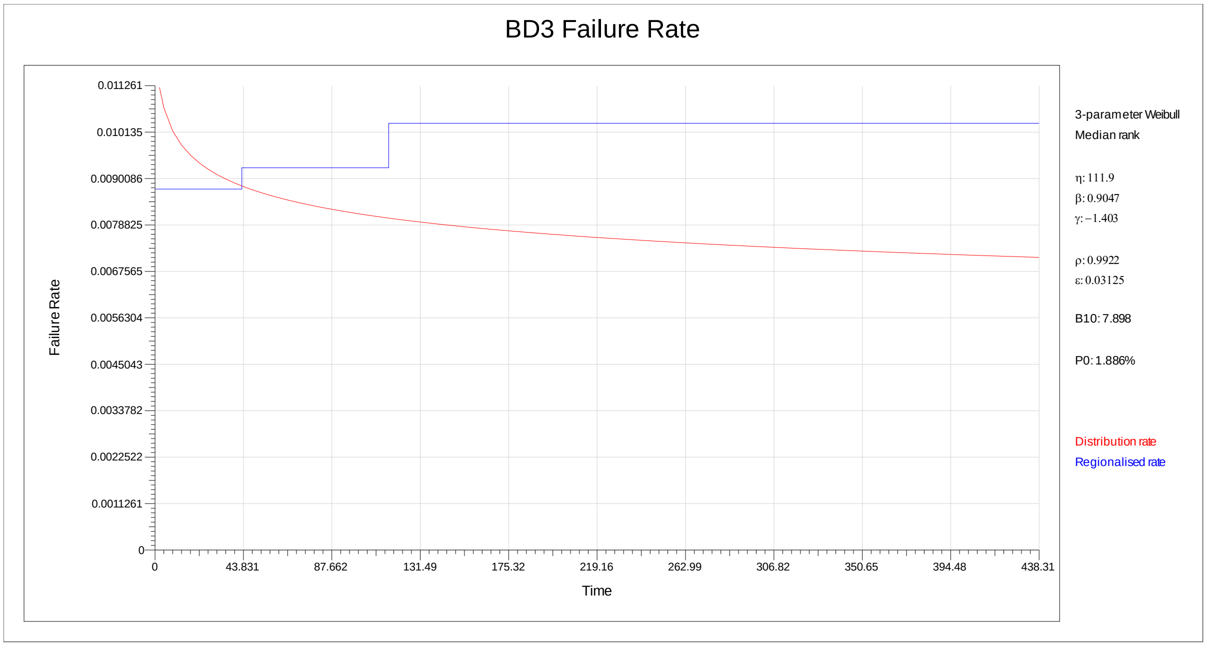


Figure 6.29 Failure rate of BD3 for β=1.018

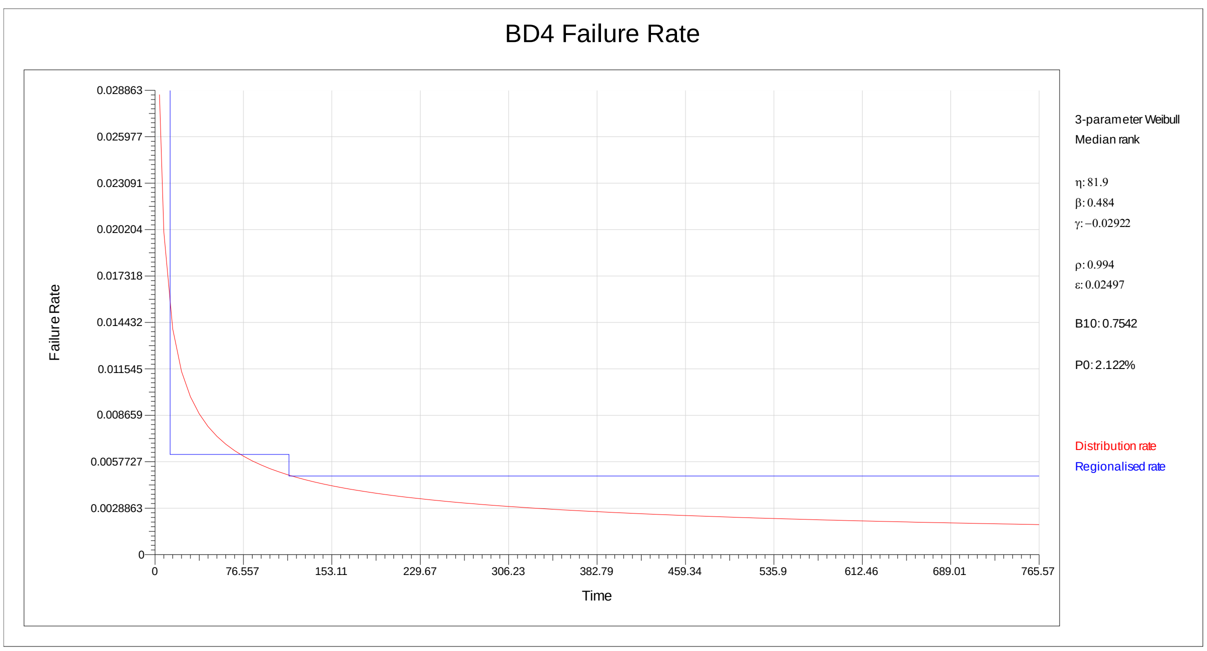


Figure 6.30 Failure rate of BD4 for β=0.5357

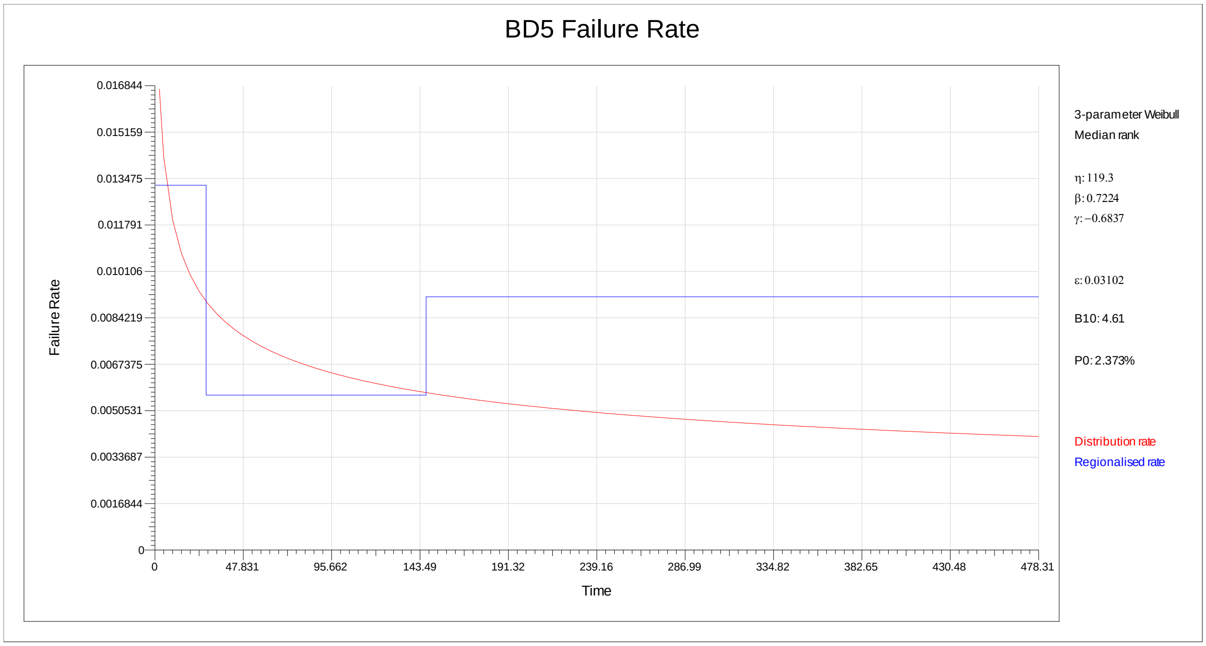


Figure 6.31 Failure rate of BD5 for β=0.9816

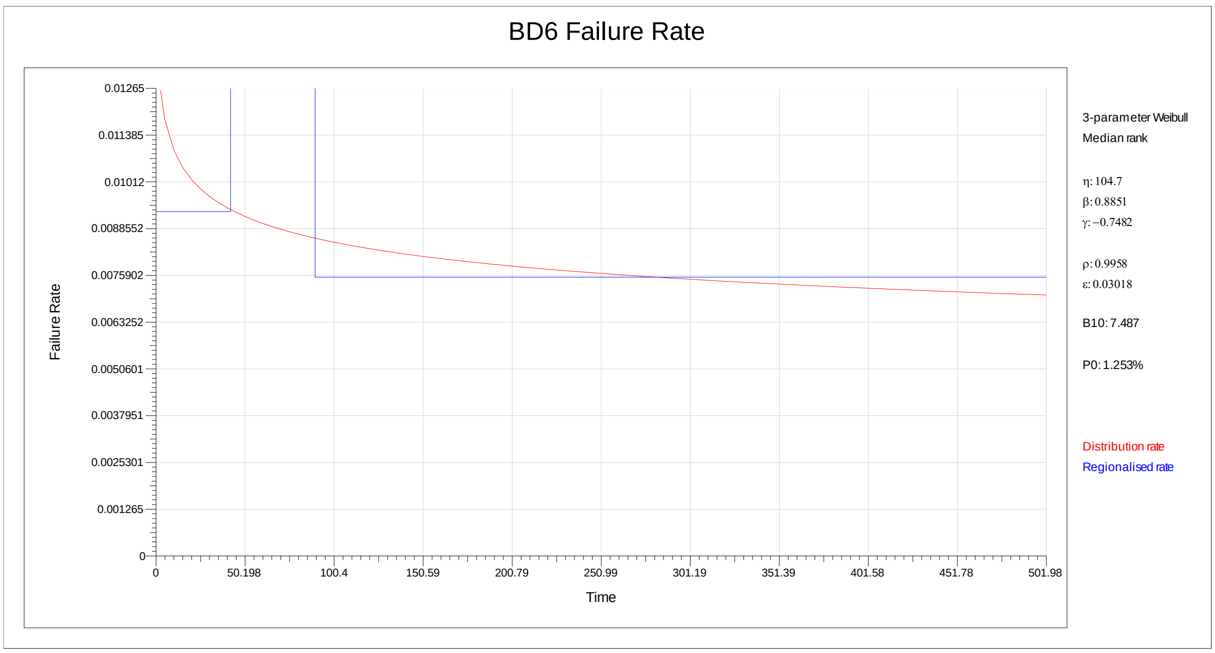


Figure 6.32 Failure rate of BD6 for β=0.9841

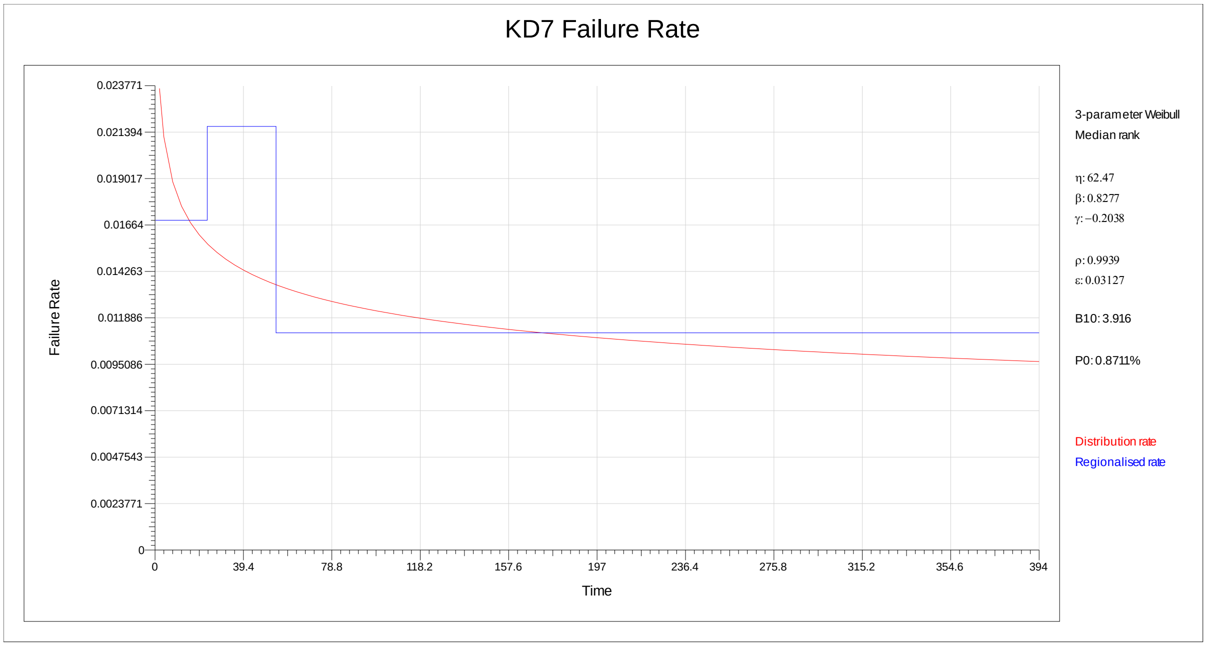


Figure 6.33 Failure rate of KD7 for β=0.7858

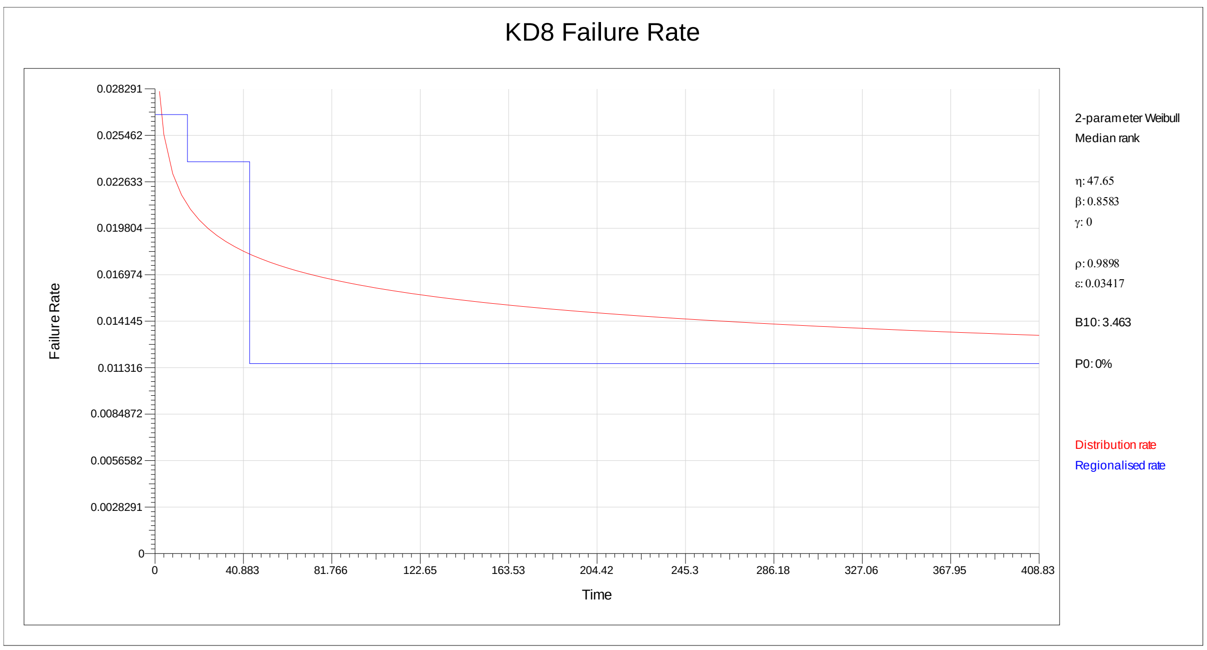


Figure 6.34 Failure rate of KD8 for β=0.8578

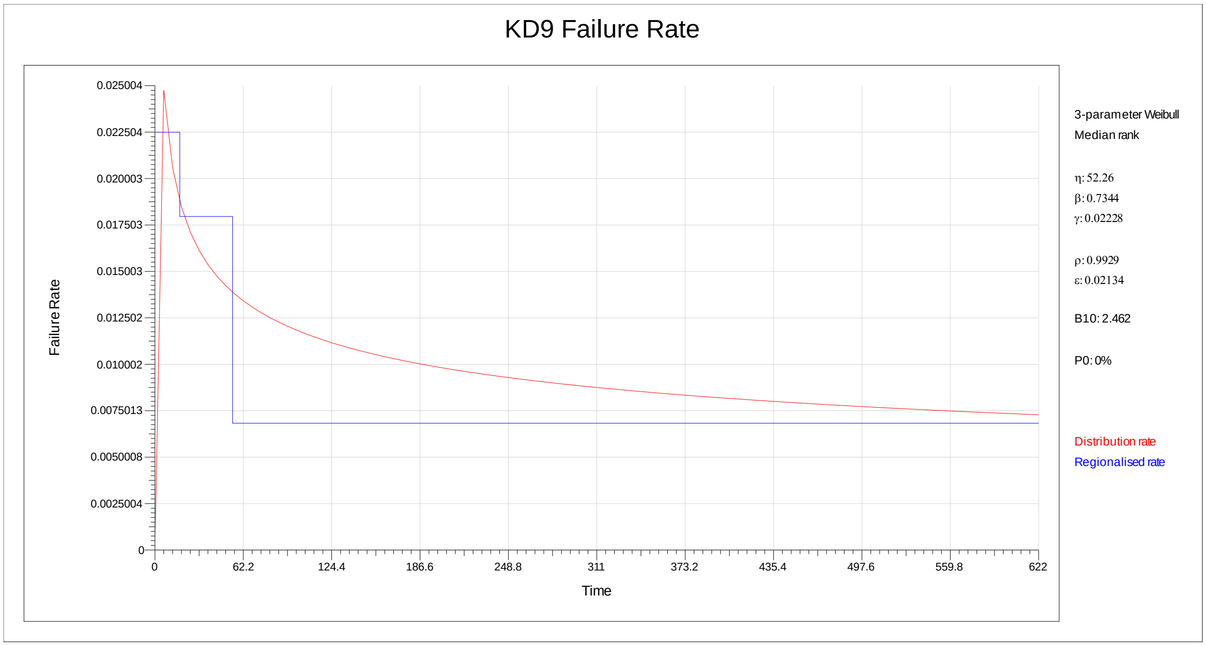


Figure 6.35 Failure rate of KD9 for β=0.7725

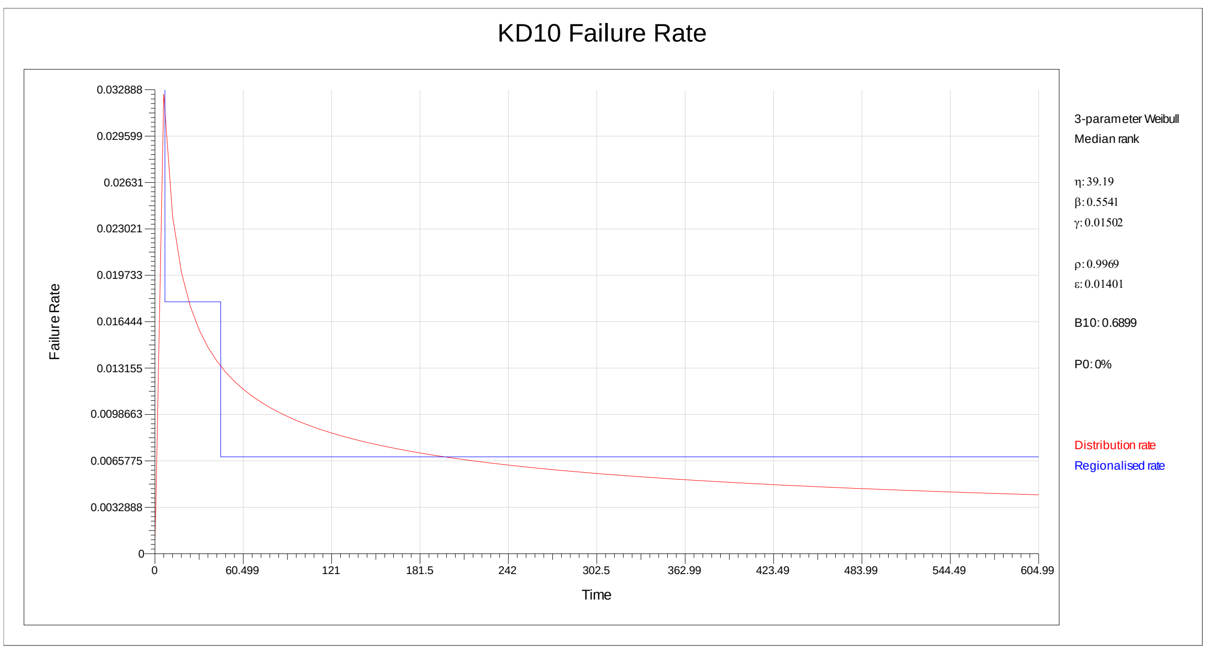


Figure 6.36 Failure rate of KD10 for β=0.542

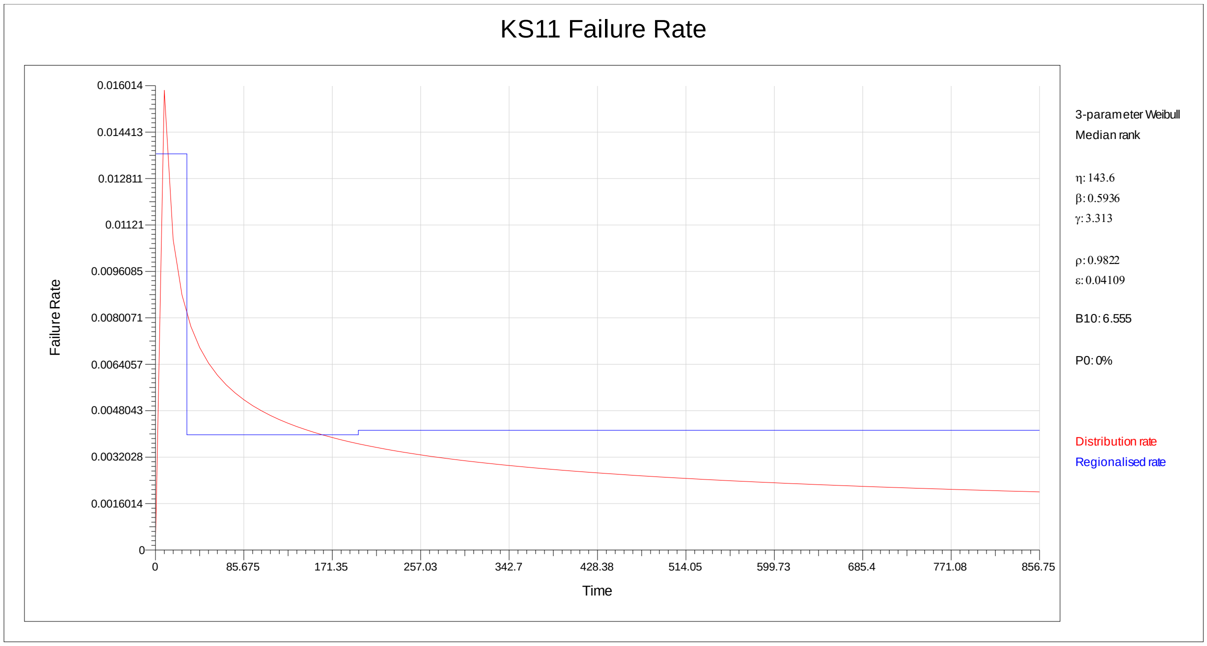


Figure 6.37 Failure rate of KS11 for β=0.5936

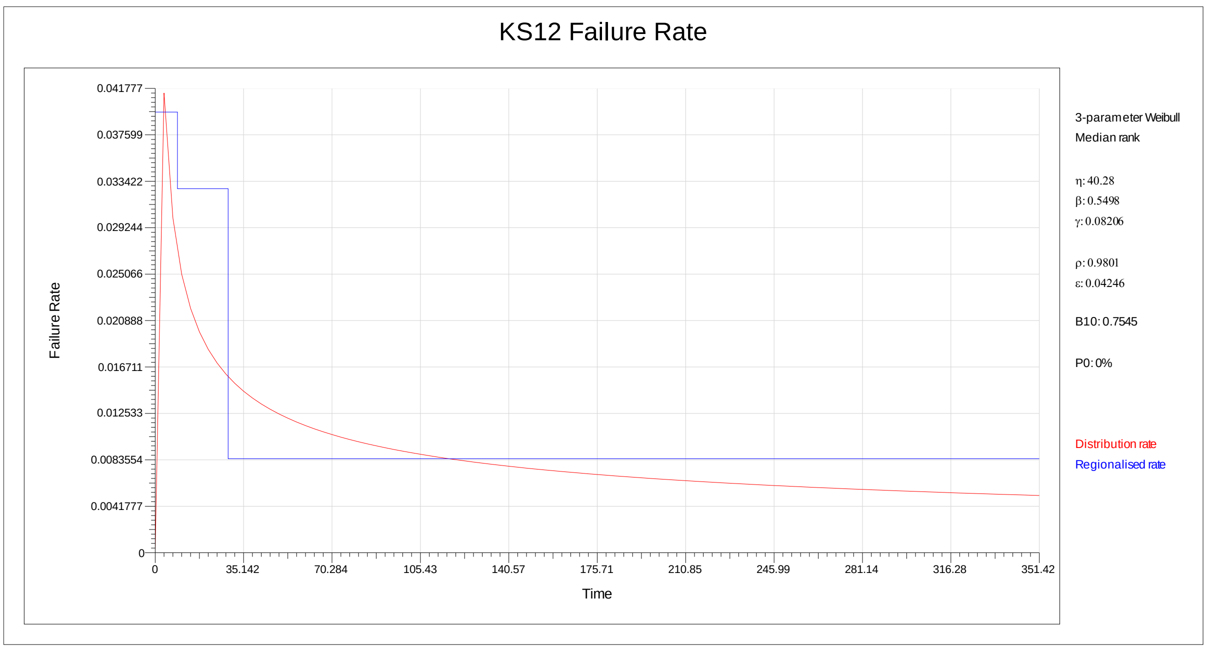


Figure 6.38 Failure rate of KS12 for β=0.5557

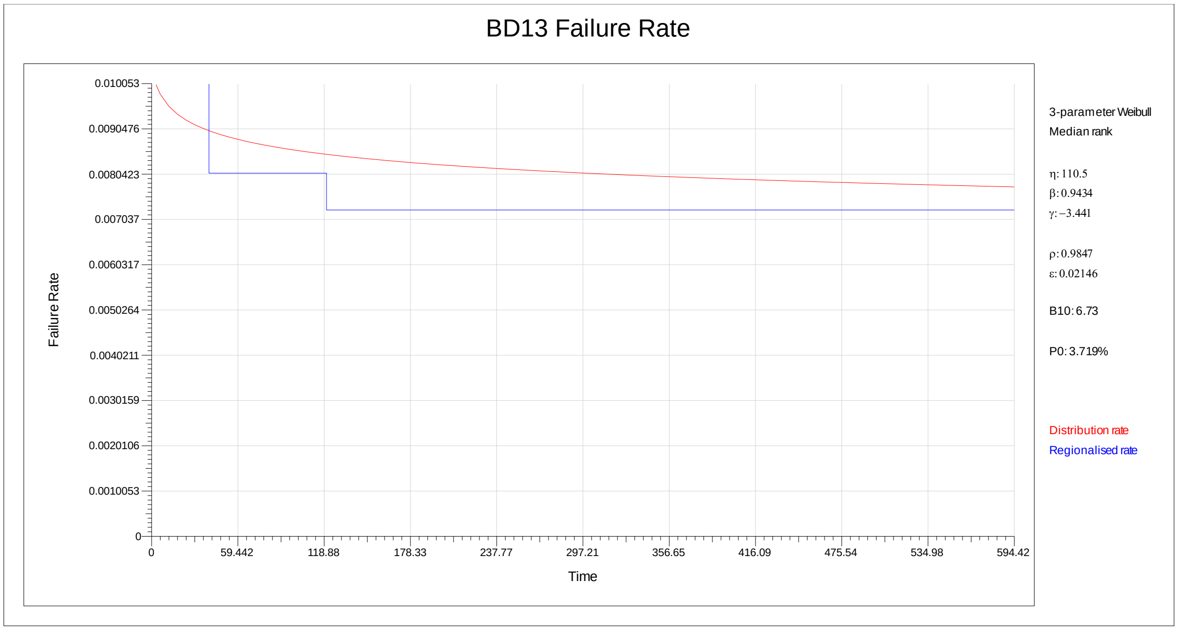


Figure 6.39 Failure rate of BD13 for β=0.9434

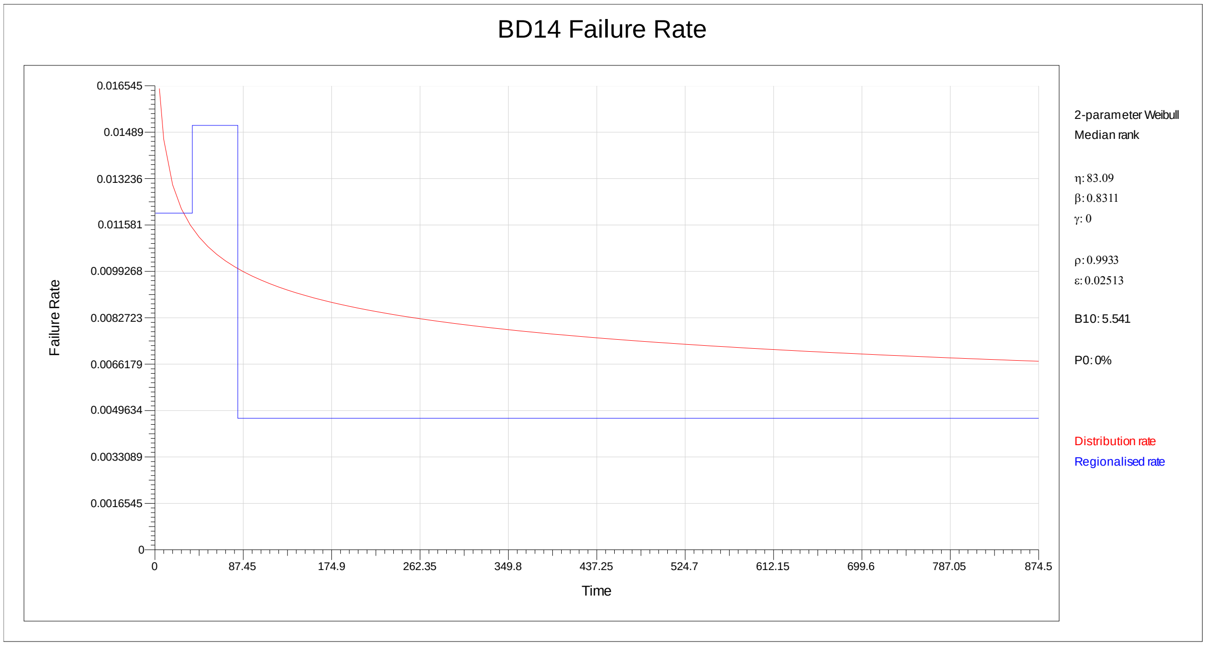


Figure 6.40 Failure rate of BD14 for β=0.8311

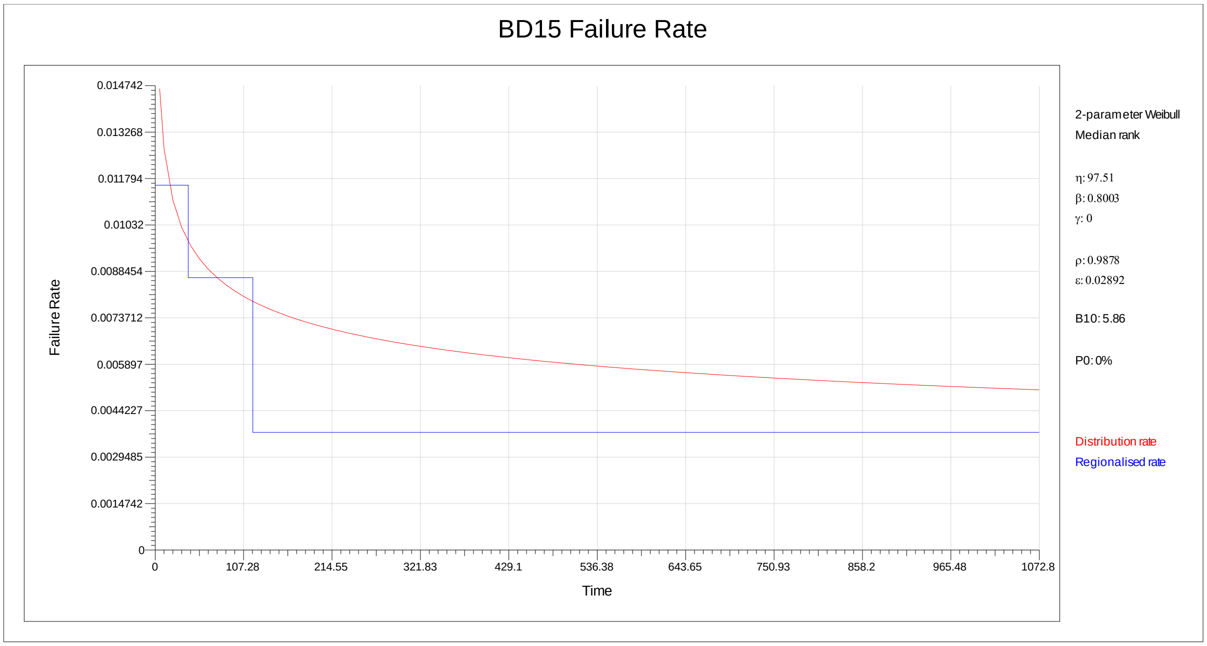


Figure 6.41 Failure rate of BD15 for β=0.8

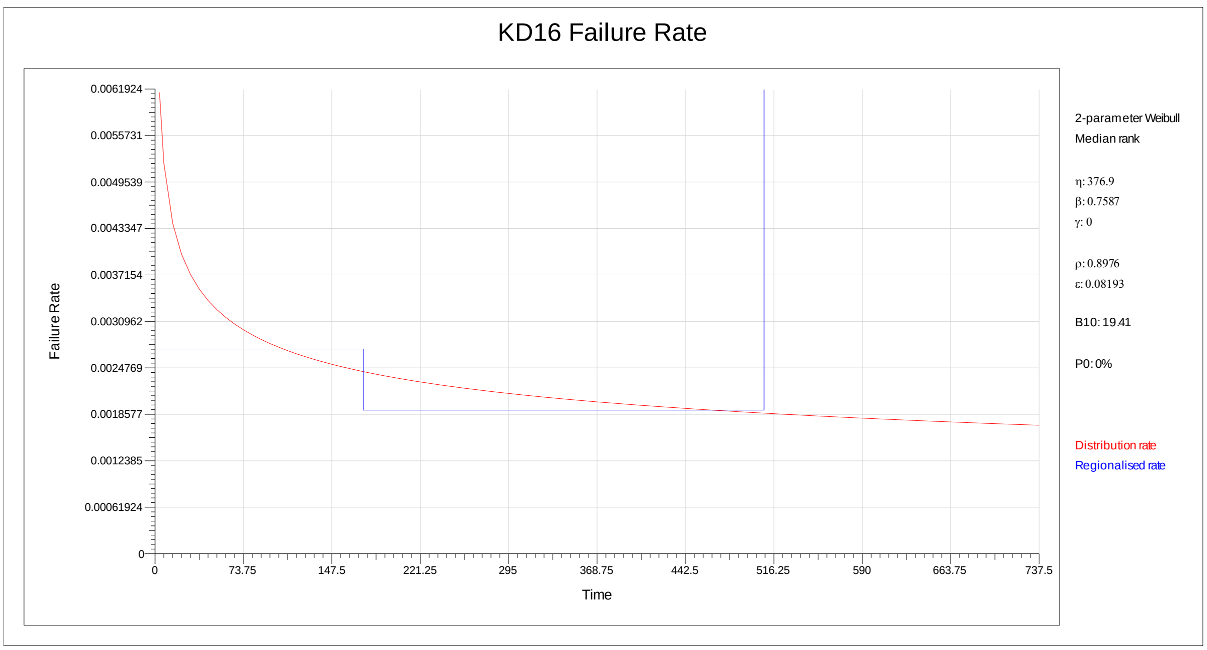


Figure 6.42 Failure rate of KD16 for β=0.7587

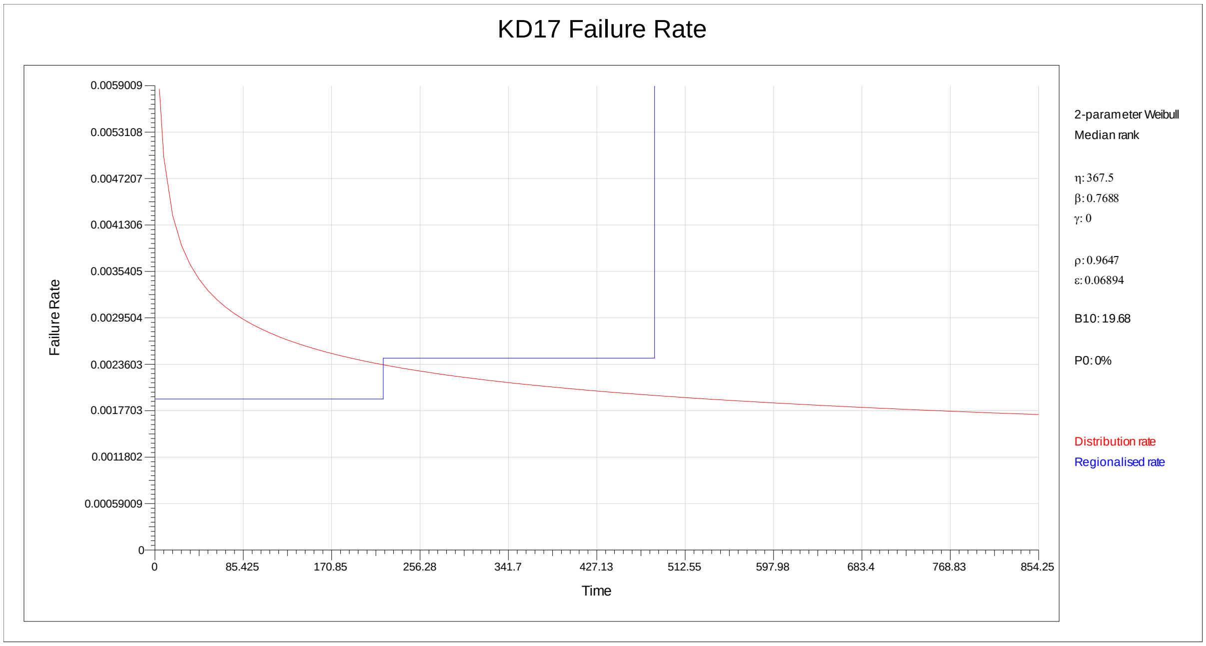


Figure 6.43 Failure rate of KD17 for β=0.7688

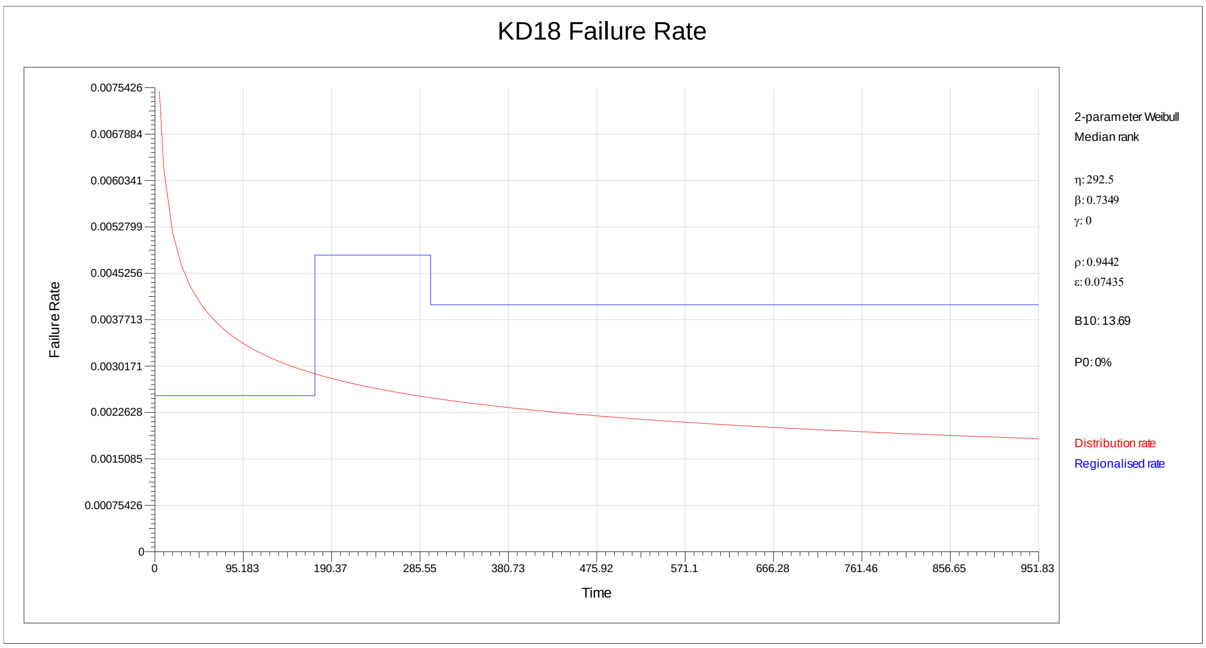


Figure 6.44 Failure rate of KD18 for β=0.7349

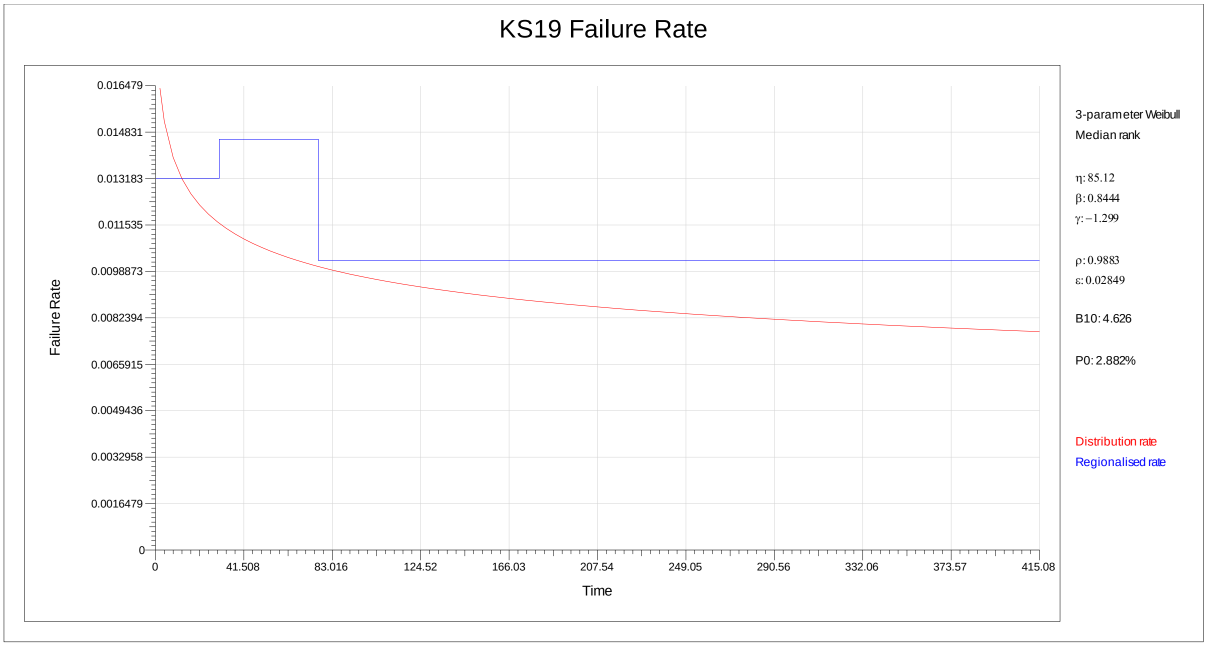


Figure 6.45 Failure rate of KS19for β=0.84

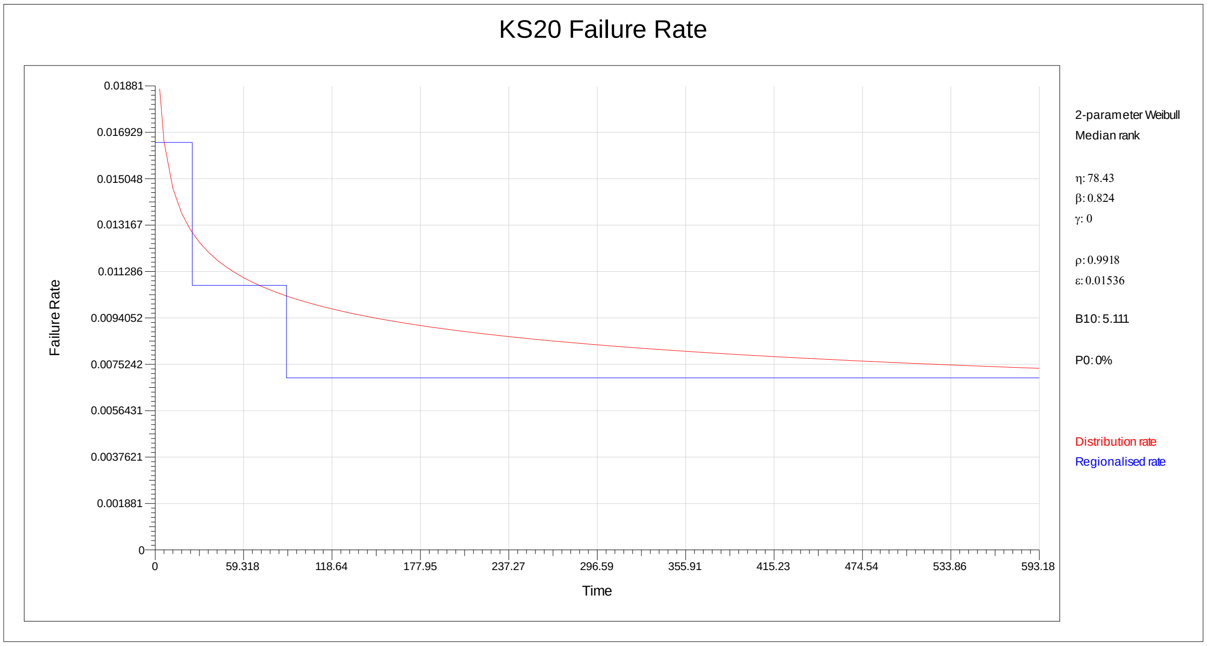


Figure 6.46 Failure rate of KS20 for β=0.82

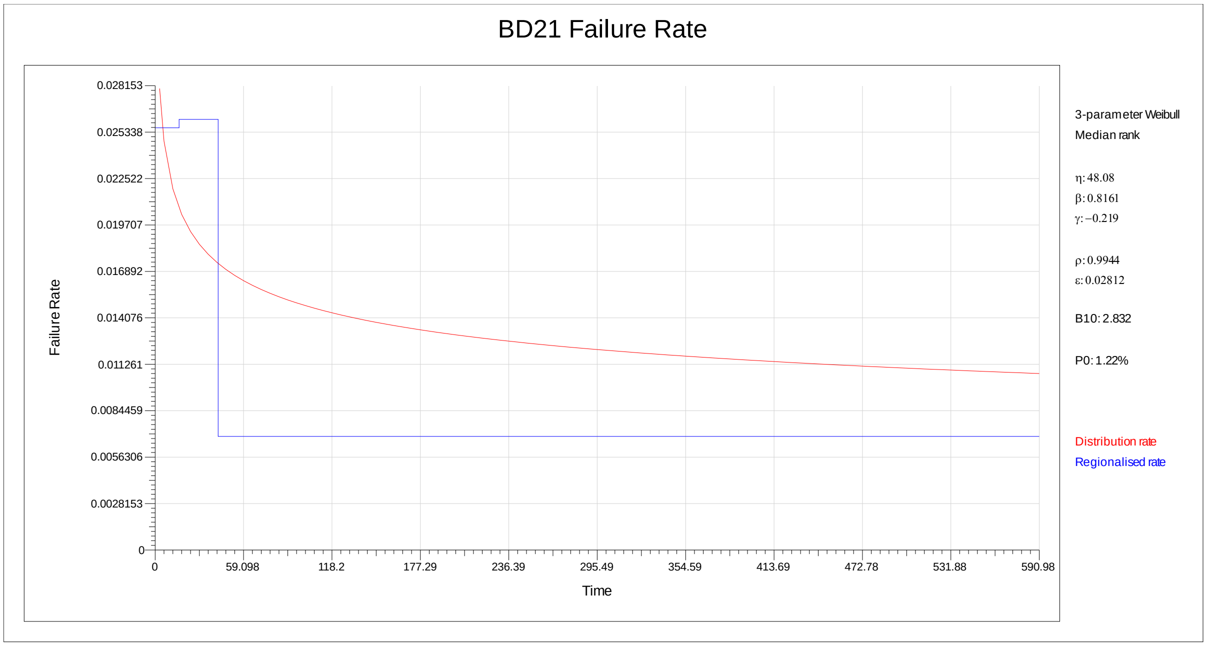


Figure 6.47 Failure rate of BD21 for β=0.81

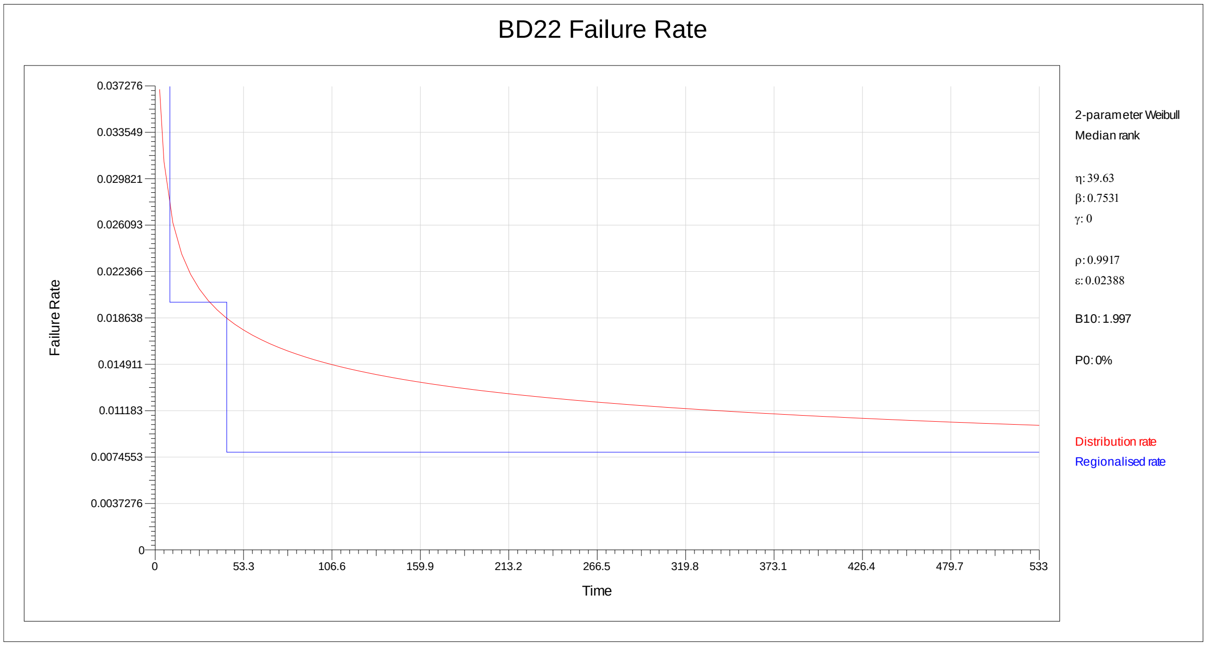


Figure 6.48 Failure rate of BD22 for β=0.75

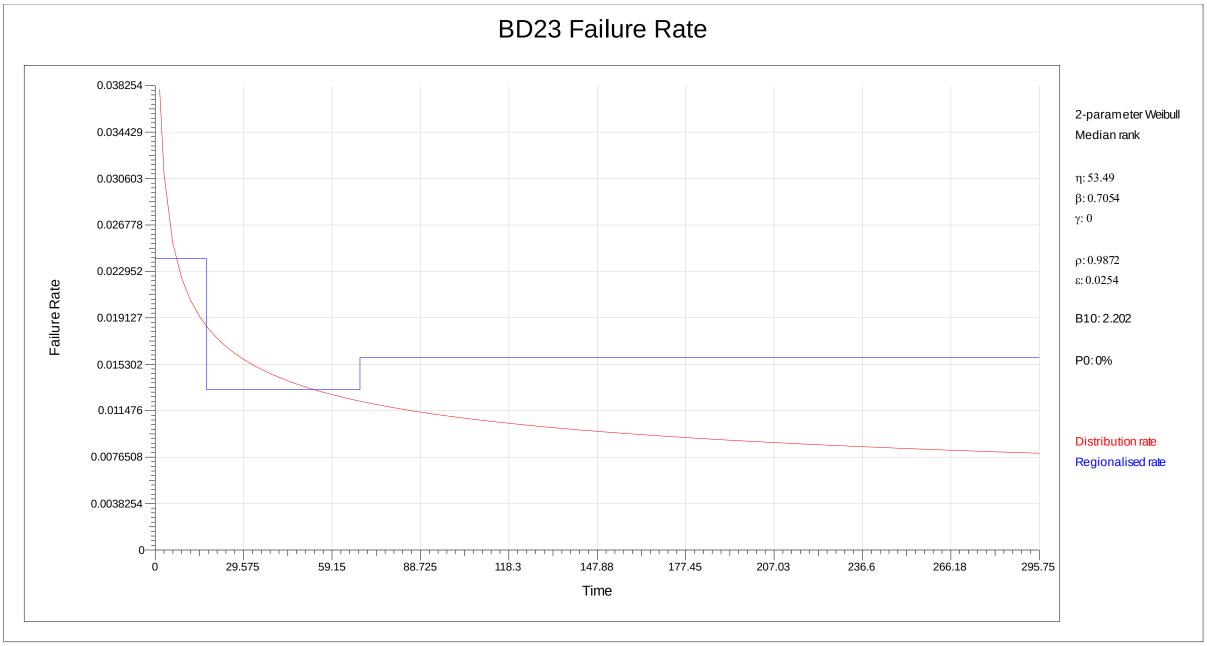


Figure 6.49 Failure rate of BD23 for β=0.71

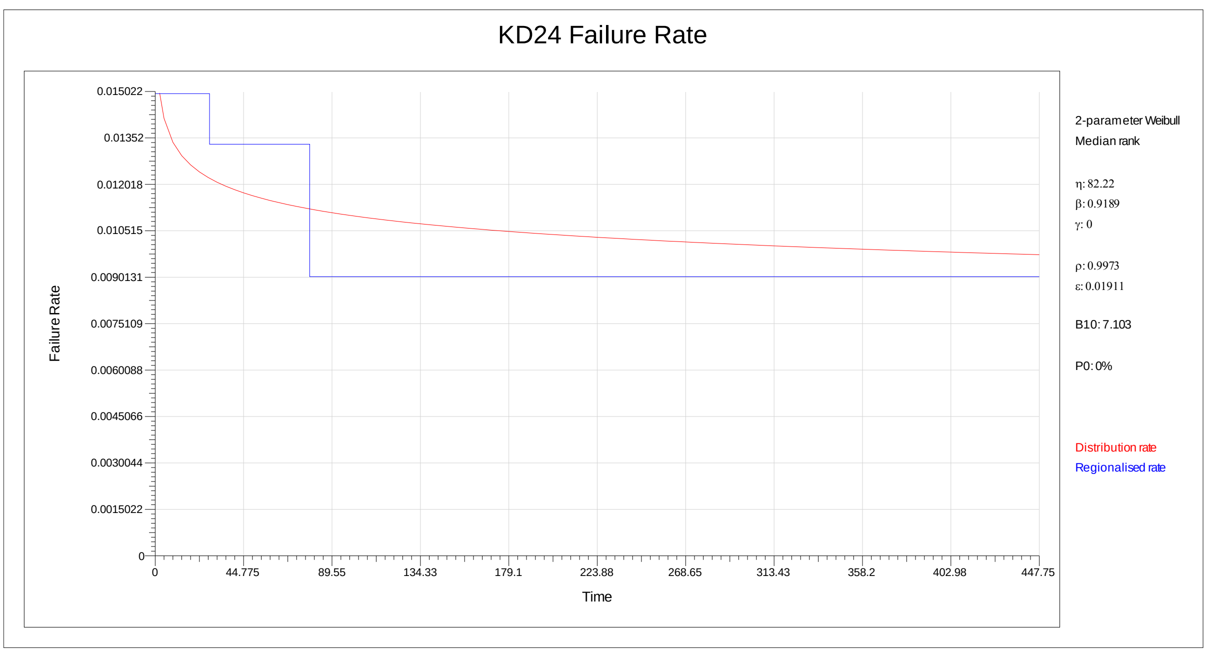


Figure 6.50 Failure rate of KD24 for β=0.92

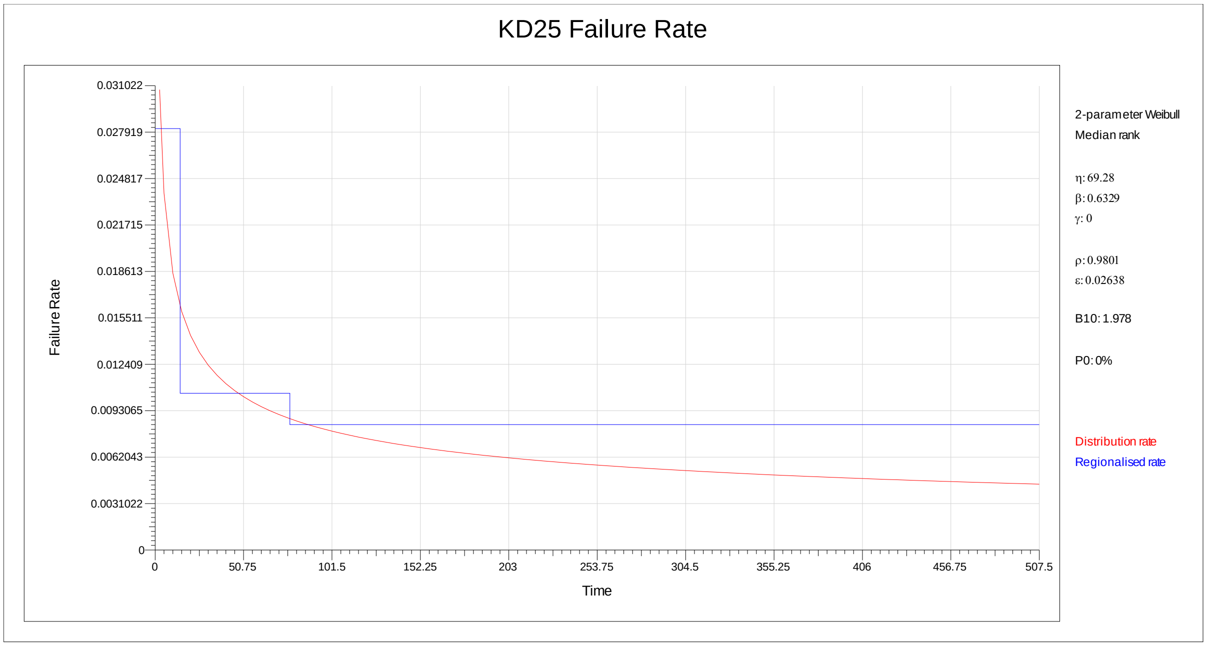


Figure 6.51 Failure rate of KD25 for β=0.63

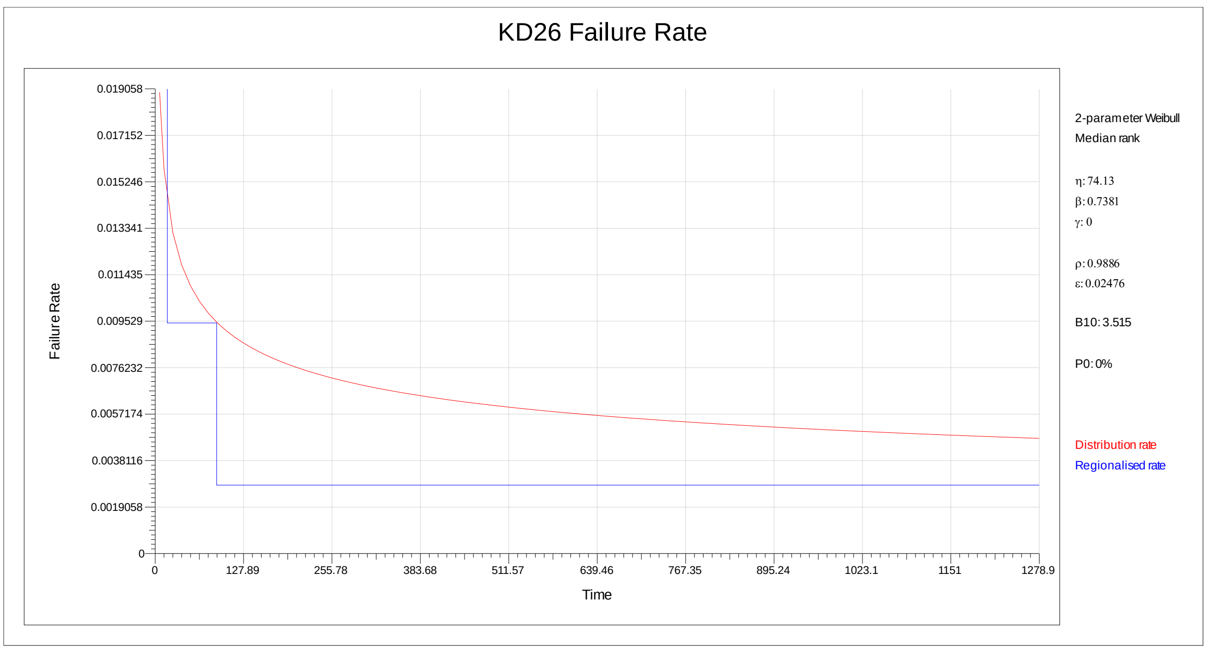


Figure 6.52 Failure rate of KD26 for β=0.74

CHAPTER 7

RAM AND PREVENTIVE MAINTENANCE OF SHOVEL AND DUMPER

7. 1 Reliability Analysis of Shovel-Dumper System for Different Time

Reliability of each shovel and dumper was determined from the corresponding best-fit distribution functions using Isograph Reliability Workbench (RWB). The best-it functions which are used for calculating the reliability of two shovels (KS1 & KS2) and eight dumpers (BD3, BD4, BD5, BD6, KD7, KD8, KD9 and KD10) in the surface coal mine as given in Table 6.14. The reliability of each shovel and dumper in the surface coal mine is determined for particular down time and 10 optional working hours (i.e., 10hrs, 20hrs, 30hrs, 40hrs, 50hrs, 60hrs, 70hrs, 80hrs, 90hrs and 100hrs). These obtained results are tabulated in Table 7.1 and it indicates reliability of shovel and dumper based on their company made i.e., (i) Reliability of KS2 (R=0.285) is less than KS1 (R=0.373) because KS2 having more repair hours than KS1 (refer Table 5.5). (ii) Reliability of BD4 (R=0.269) is less than BD3 (R=0.356), BD5 (R=0.347) and BD6 (R=0.334) because more number of failures and more repair hours in BD4 than BD3, BD5 and BD6 (refer Table 5.5), (iii) Reliability of KD8 (R=0.275) and KD9 (R=0.268) are less than KD7 (R=0.332) and KD10 (R=0.291) because more number of failure and less MTBF in KD8 and KD9 than KD7 and KD10 (refer Table 5.5).

In surface iron ore mine, the best fit functions which are used for calculating the reliability of two shovels (KS11 and KS12) and six dumpers (BD13, BD14, BD15, KD16, KD17 and KD18) in surface iron ore mine are as given in Table 6.14. The reliability of each shovel and dumper is determined for particular downtime and 10 optional working hours (i.e., 10hrs, 20hrs, 30hrs, 40hrs, 50hrs, 60hrs, 70hrs, 80hrs, 90hrs and 100hrs). These obtained results are tabulated in Table 7.1 and it clearly indicates reliability of shovel and dumper based on their company made i.e., (i) Reliability of KS12 (R=0.275) is less than KS11 (R=0.312) because more number of failure and more repair hours in KS12 than KS11 (refer Table 5.9), (ii)

Reliability of BD13 (R=0.359), BD14 (R=0.0.342) and BD15 (R=0.332) are almost equal, but less reliability than KD16 (R=0.409), KD17 (R=0.393) and KD18 (R=0.394) because more number of failures and less MTBF in BD13, BD14 than BD15.

Similarly, in case of surface limestone mine the best fit functions which is used for calculating the reliability of two shovels (KS19 and KS20) and six dumpers (BD21, BD22, BD23, KD24, KD25, KD26) mine are as given in Table 6.14. The reliability of each shovel and dumper is determined for particular downtime and 10 optional working hours (i.e., 10hrs, 20hrs, 30hrs, 40hrs, 50hrs, 60hrs, 70hrs, 80hrs, 90hrs and 100hrs). These obtained results are tabulated in Table 7.1 and it indicates reliability of shovel and dumper based on their company made i.e., (i) Reliability of KS19 and KS20 almost equal and good reliability compared to other two surface mine i.e., coal mine and iron ore mine and (ii) In dumpers, reliability of the BD22 (R=0.292) is less than others i.e., BD21 (R=0325), BD23 (R=0.329), KD24 (R=0.362), KD25 (R=0.334) and KD26 (R=0.304).

Table 7.1 Reliability of each shovel and dumper

	Systems	**MTBF (t)**	**R(t)**	**Reliability (R) for different time (t in hrs)**									
				t=10	**t=20**	**t=30**	**t=40**	**t=50**	**t=60**	**t=70**	**t=80**	**t=90**	**t=100**
Surface coal mine	KS1	43.834	0.373	0.89	0.818	0.75	0.688	0.631	0.579	0.53	0.486	0.445	0.408
	KS2	49.567	0.285	0.722	0.626	0.559	0.508	0.466	0.431	0.401	0.375	0.352	0.331
	BD3	110.12	0.356	0.864	0.793	0.731	0.675	0.625	0.579	0.538	0.5	0.465	0.432
	BD4	126.834	0.269	0.881	0.797	0.724	0.658	0.599	0.547	0.499	0.456	0.417	0.382
	BD5	127.63	0.347	0.789	0.665	0.571	0.495	0.433	0.38	0.336	0.297	0.264	0.236
	BD6	139.896	0.334	0.769	0.622	0.511	0.423	0.353	0.296	0.249	0.21	0.178	0.152
	KD7	67.365	0.332	0.754	0.618	0.519	0.441	0.378	0.326	0.283	0.247	0.216	0.19
	KD8	53.056	0.275	0.62	0.499	0.42	0.363	0.319	0.283	0.253	0.229	0.207	0.189
	KD9	58.673	0.268	0.632	0.472	0.366	0.291	0.236	0.193	0.159	0.132	0.111	0.093
	KD10	62.516	0.291	0.682	0.53	0.426	0.348	0.289	0.242	0.204	0.174	0.148	0.127
Iron ore mine	KS11	189	0.312	0.85	0.756	0.691	0.64	0.598	0.562	0.53	0.502	0.476	0.453
	KS12	59.38	0.275	0.62	0.495	0.414	0.355	0.31	0.273	0.243	0.218	0.197	0.178
	BD13	109.7	0.359	0.871	0.792	0.722	0.659	0.603	0.552	0.506	0.464	0.425	0.39
	BD14	90.36	0.342	0.841	0.736	0.651	0.58	0.519	0.466	0.42	0.379	0.343	0.311
	BD15	110	0.332	0.85	0.754	0.677	0.612	0.556	0.507	0.464	0.425	0.391	0.36
	KD16	324.4	0.409	0.938	0.897	0.863	0.833	0.805	0.78	0.756	0.734	0.713	0.693
	KD17	336	0.393	0.938	0.898	0.863	0.833	0.805	0.779	0.755	0.733	0.711	0.691
	KD18	265.6	0.394	0.92	0.87	0.829	0.793	0.761	0.732	0.705	0.68	0.657	0.635

Limestone mine	KS19	91.06	0.343	0.832	0.732	0.65	0.58	0.52	0.468	0.422	0.382	0.346	0.314
	KS20	83.69	0.348	0.831	0.722	0.635	0.562	0.501	0.448	0.402	0.362	0.326	0.295
	BD21	55.37	0.325	0.752	0.609	0.503	0.421	0.355	0.301	0.257	0.22	0.189	0.163
	BD22	52.23	0.292	0.7	0.549	0.444	0.365	0.304	0.255	0.216	0.184	0.157	0.135
	BD23	62.17	0.329	0.738	0.608	0.515	0.443	0.385	0.338	0.298	0.264	0.235	0.21
	KD24	83.7	0.362	0.866	0.762	0.673	0.597	0.531	0.473	0.422	0.377	0.337	0.302
	KD25	80.09	0.334	0.744	0.633	0.554	0.493	0.443	0.401	0.365	0.335	0.308	0.284
	KD26	93.71	0.304	0.797	0.684	0.599	0.531	0.474	0.425	0.383	0.347	0.315	0.287

Figure 7.1 shows the reliability curve for considered systems (i.e., Shovel: KS1 and KS2) and dumpers (BD3, BD4, BD5, BD6, KD7, KD8, KD9 and KD10) in surface coal mine with different MTBF values. Also, Figure 7.2 and Figure 7.3 shows that the graph of the reliability curve for considered systems in surface iron ore mine (i.e., Shovel: KS11 and KS12 and dumpers: BD13, BD14, BD15, KD16, KD17 and KD18) and surface limestone mine (i.e., Shovel: KS19 & KS20 and dumpers: BD21, BD22, BD23, KD24, KD25 and KD26) with different MTBF values. However, the Figure 7.1 for surface coal mine, 7.2 for surface iron ore mine and 7.3 for surface limestone mine are drawn between the reliability and TBF (TBF for 5400 hours in surface coal mine, for 3900 hours in surface iron ore mine and for 4200 hours in surface limestone mine) of shovel and dumper. It is observed that larger the MTBF the better the reliability over time. The nature of the reliability trend in each shovel and dumper is decreasing and 0% of reliability at the end of the working hours due to higher number of failures and higher repair hours.

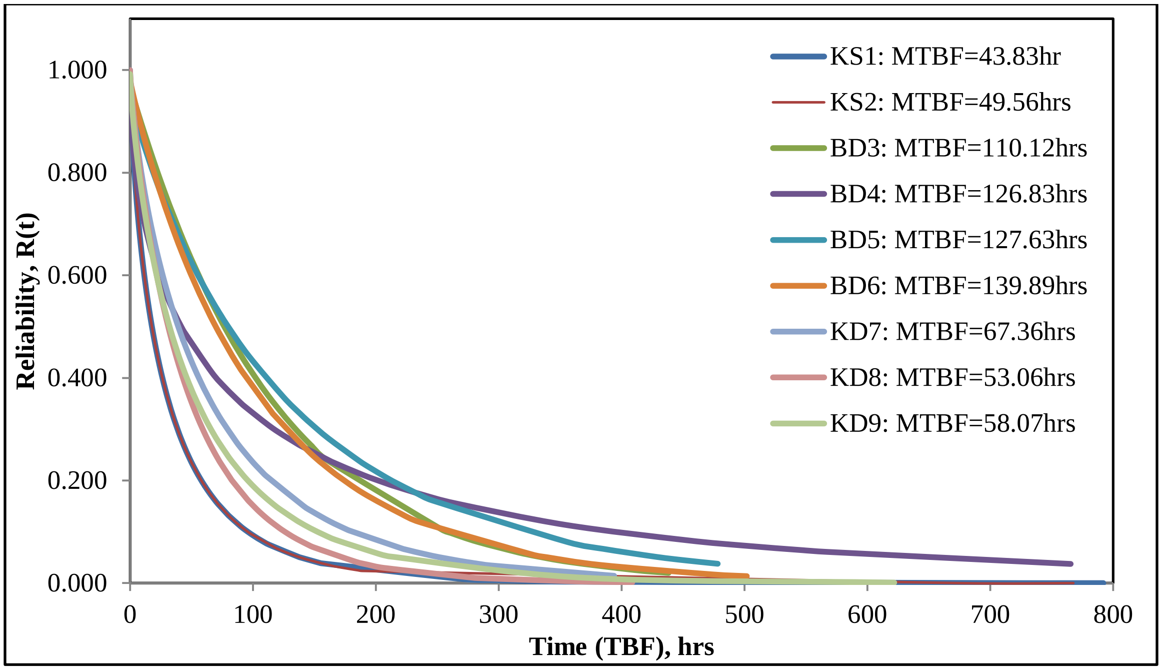


Figure 7.1 Reliability each shovel and dumper in surface coalmine

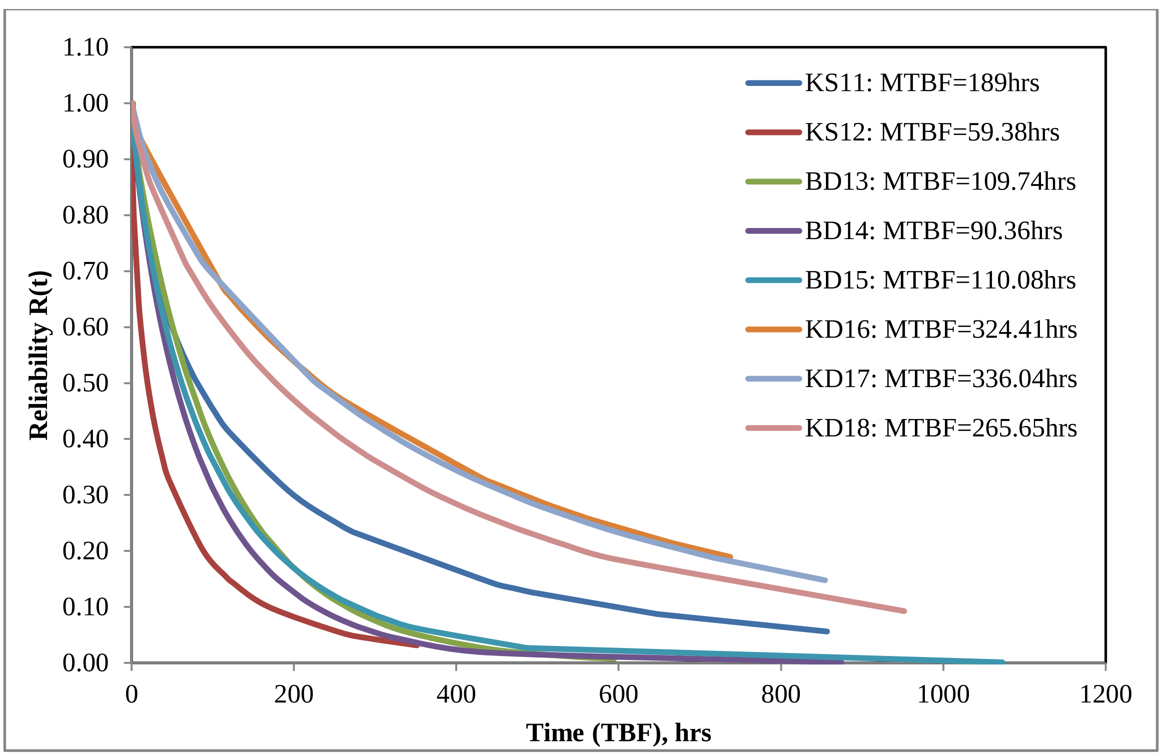


Figure 7.2 Reliability each shovel and dumper in surface iron ore mine

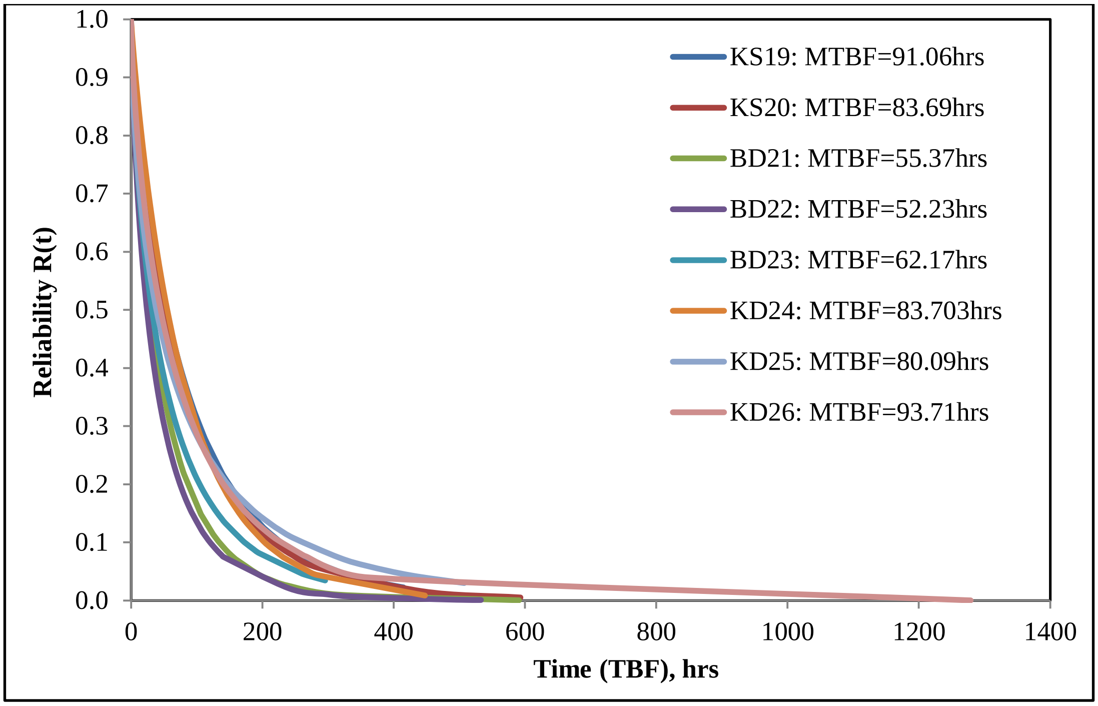


Figure 7.3 Reliability each shovel and dumper in surface limestone mine

7.2 Availability and Maintainability of Shovel-Dumper System

Availability and maintainability of each shovel and dumper in all three surface mines were determined by using equations (2.27) and (2.29). The MTBF for each shovel and dumper were determined by dividing the CTBF with the total number of failures. Similarly, the MTTR of the each shovel and dumper was determined by dividing the CTTR with the total number of failures. The respective values of MTBF and MTTR for each system (shovel and dumper) along with the number of failures for all three surface mines are given in Table 7.2. It is clear from the results availability for shovels and dumpers ranges from 0.7636 (76.36%) to 0.9033 (90.33%) for 5400 operated hours, from 0.7636 (76.36%) to 0.9033 (90.33%) for 3900 operated hours and from 0.7636 (76.36%) to 0.9033 (90.33%) for 4200 operated hours respectively for the surface coal mine, surface iron ore mine and surface limestone mine. Also, Maintainability ‘1’ indicates that the machine is less prone to undergo service/ less repairable.

Table 7.2 Availability and maintainability of shovel-dumper system

Type of the Mine	Systems	No. of Failures	MTBF	MTTR	Availability	Maintainability
Surface coal Mine	KS1	181	43.8339	4.6928	0.9033	0.9999
	KS2	157	49.5671	7.4869	0.8688	0.9987
	BD3	56	110.12	34.0958	0.7636	0.9604
	BD4	46	126.8338	32.6117	0.7955	0.9795
	BD5	41	127.6303	38.0602	0.7703	0.965
	BD6	45	139.8964	18.5523	0.8829	0.9995
	KD7	88	67.3649	21.135	0.7612	0.9587
	KD8	141	53.0565	7.3314	0.8786	0.9993
	KD9	97	58.6729	12.7652	0.8213	0.9899
	KD10	95	62.5162	18.7059	0.7697	0.9646
Surface iron ore mine	KS11	31	189	11.07	0.9447	1
	KS12	29	59.38	3.674	0.9417	1
	BD13	64	109.74	32.504	0.7715	0.9658
	BD14	88	90.36	14.376	0.8627	0.9981
	BD15	77	110.08	15.76	0.8748	0.9991
	KD16	20	324.41	77.94	0.8063	0.9844
	KD17	19	336.04	84.14	0.7998	0.9816
	KD18	27	265.65	36.59	0.8789	0.9993
Surface limestone mine	KS19	66	91.06	3.84	0.9595	1
	KS20	70	83.69	9.4	0.899	1
	BD21	91	55.37	15.05	0.7863	0.9748
	BD22	97	52.23	15.07	0.7761	0.9688
	BD23	76	62.17	21.83	0.7401	0.942
	KD24	58	83.703	7.49	0.9179	1
	KD25	74	80.09	8.91	0.8999	0.9999
	KD26	58	93.71	10.03	0.9033	0.9999

7. 3 Preventive Maintenance of Shovel-Dumper System

Preventive maintainence is carried out to improve the reliability of the system based on the existing reliability. Since the reliability for each system is different, the maintenance time interval for each system will also be different. Hence, calculation of preventive maintenance for each shovel and dumper system is needed to improve the productivity of surface mine. The relation for calculating the preventive maintainence is represented in equation 2.9.

The maintenance time interval for each subsystem of the shovel and dumper was determined to achieve a reliability of 90%, 80% and 70% for each system. The calculated and required time interval for maintenance to improve reliability (up to 90%, 80% and 70%) of shovel and dumper in surface coal mines in given in Table. 7.3.

Similarly, the shovel and dumper used in surface iron ore mine (KS11, KS12, BD13, BD14, BD15, KD16, KD17, KD18) and surface limestone mine (KS19, KS20, BD21, BD22, BD23, KD24, KD25 and KD26) require maintenance in hours and given in Table 7.3.

Table 7.3 Reliability based time interval for preventive maintenance

Type of Mine	**Systems**	**Level of Reliability (%)**		
		90%	**80%**	**70%**
		t in hrs		
Surface Coal Mine	KS1	12.87	14.8	17.03
	KS2	16.39	18.79	21.54
	BD3	60.2	66.83	74.13
	BD4	26.88	32.44	39.15
	BD5	60.36	68.09	76.74
	BD6	54.01	60.3	67.29
	KD7	29.17	33.13	37.63
	KD8	23.68	26.61	29.9
	KD9	23.76	27.06	30.81
	KD10	12.9	15.51	18.65
Surface Iron Ore	KS11	20.7961	14.786	28.6396
	KS12	12.8298	2.5806	18.3656
	BD13	25.79	18.963	33.4981
	BD14	18.4653	13.668	24.0613
	BD15	20.4392	14.953	26.9088
	KD16	72.5608	52.191	96.9693
	KD17	72.2992	52.228	96.252
	KD18	53.3862	37.991	72.017
Surface Limestone	KS19	12.9737	24.584	45.6388
	KS20	12.5904	23.1662	42.6254
	BD21	7.327	13.7704	25.7157
	BD22	5.3633	10.4464	20.3467
	BD23	6.4677	13.0795	26.4503
	KD24	16.1023	27.728	47.7472
	KD25	6.4058	14.1661	31.3278
	KD26	9.7649	19.1915	37.7183

CHAPTER 8

RELIABILITY BLOCK DIAGRAM

8.1 RBD Analysis of Subsystems of each Shovel and Dumper

The structure of a reliability block diagram (RBD) defines the logical interaction of failures within a system. Individual blocks may represent single component failures, sub-system failures and other events that may contribute towards system failures. The reliability behavior of an individual sub-system block may be represented by a RBD at a lower hierarchical level. The logical flow of a RBD originates from an input node at the left-hand side of the diagram to an output node at the right-hand side of the diagram. Blocks are arranged in series arrangement between the system input and output nodes.

In this chapter, RBD analysis for shovels (i.e., in surface coal mine: KS1, KS2, in surface iron ore mine: KS11, KS12, in surface limestone mine: KS19, KS20) and dumpers (in surface coal mine: BD3, BD4, BD5, BD6, KD7, KD8, KD9, KD10, in surface iron ore mine: BD13, BD14, BD15, KD16, KD17, KD18, in surface limestone mine: BD21, BD22, BD23, KD24, KD25, KD26) is carried out to find overall reliability of the system, when all subsystems are connected in series. In this series network, if one subsystem fails, the whole system will be shut down. That means the failure of a single component will stop the complete system process. The effect of each failed subsystem on overall system performance using Fussell-Vesely importance is also determined. There are two possible networks to identify the subsystem and to predict the overall reliability of each shovel and dumper. They are (i) Series configuration, (ii) Series-parallel configuration.

8.1.1 Series configuration

For the system to be successful in its operation, at least one path must be maintained between the system input and output nodes. A series arrangement of 10 subsystems in each shovel and dumper (i.e., subsystems SS1 to SS10 in shovels and subsystems DS1 to DS10 in dumpers) would require only one of the subsystems to fail to eliminate the single success path from input to output node.

The RBD analysis of one shovel (out of 6 shovels from all three mines) and one dumper (out of 22 dumpers from all three mines) from each mine are given here and remaining shovels (5 shovels) and dumpers (21 dumpers) are given in Annexure-D.

The 10 subsystems of shovel: KS1 (i.e., SS1 to SS10 as given in Table 5.3) and 10 subsystems of dumper: BD3 (i.e., DS1 to DS10 as mentioned in Table 5.3) in surface coal mine are connected in the series configuration as shown in Figure 8.1 and 8.2. Similarly, RBD is analysed for KS11 (shovel) and BD13 (dumper) from iron ore mine and KS19 (shovel) and BD21 (dumper) from surface limestone mine. The subsystems of KS11, BD13, KS19 and BD21 (refer Table 5.3 for subsystems) are connected in series configuration as shown in Figures 8.3, 8.4, 8.5 and 8.5. The RBD of other shovels (KS2, KS12 and KS20) and dumpers (BD4, BD5, BD6, KD7, KD8, KD9, KD10, BD14, BD15, KD16, KD17, KD18, BD22, BD23, KD24, KD25, KD26) are given in Section D.1, Annexure – D. In all shovels and dumper having single unit subsystems and there is no any standby. Moreover, RBD of all these shovel and dumpers are constructed based on the failure rate of their subsystems using Isograph Reliability Workbench. The outcomes of the analysing the constructed RBD models resulted in reliability, as tabulated in Table 8.1. the obtained reliabilty are further compared to those reliability calculate based on TBF and TTR data collected from mines. It was found similar with negligible error.

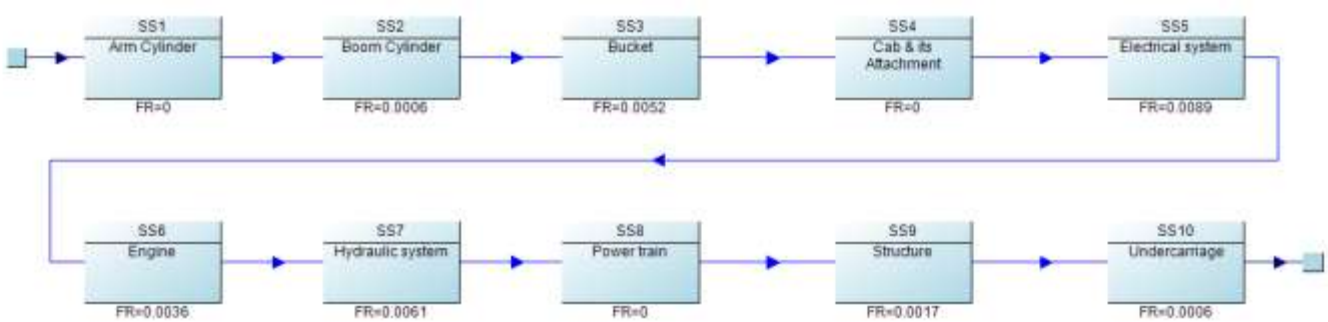


Figure 8.1 RBD of shovel - KS1

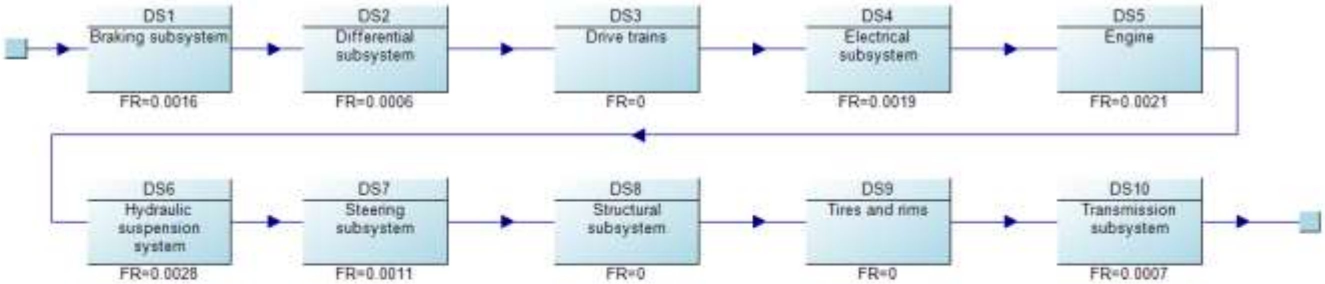


Figure 8.2 RBD of dumper – BD3

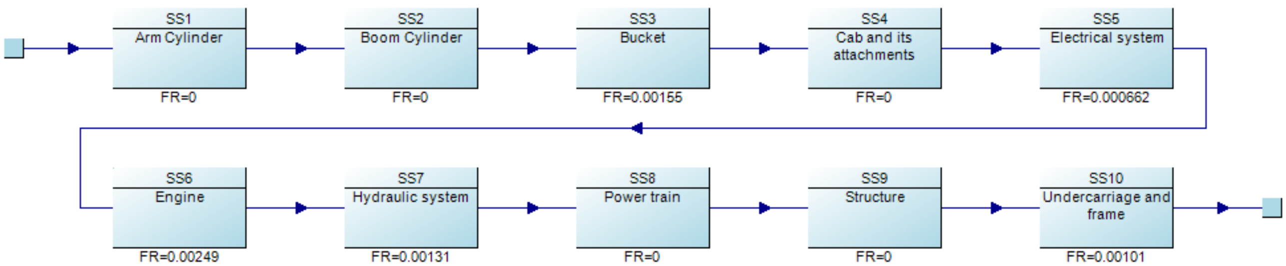


Figure 8.3 RBD of shovel - KS11

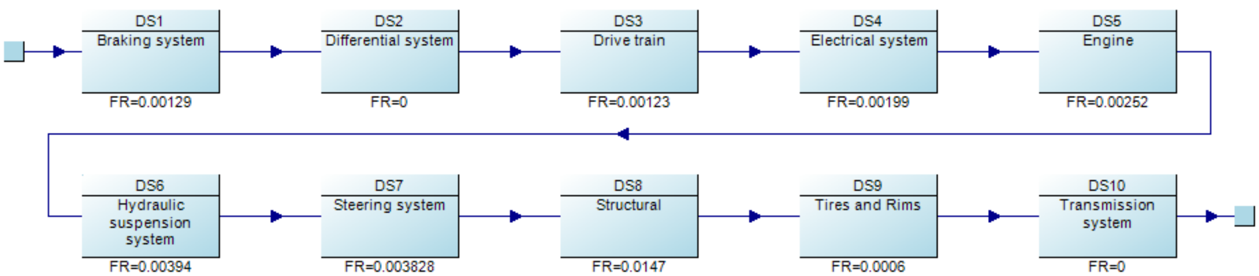


Figure 8.4 RBD of dumper – BD13

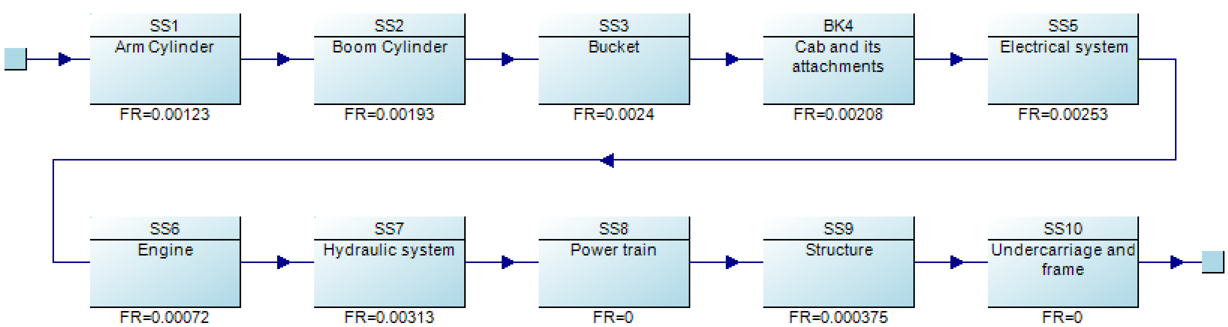


Figure 8.5 RBD of shovel - KS19

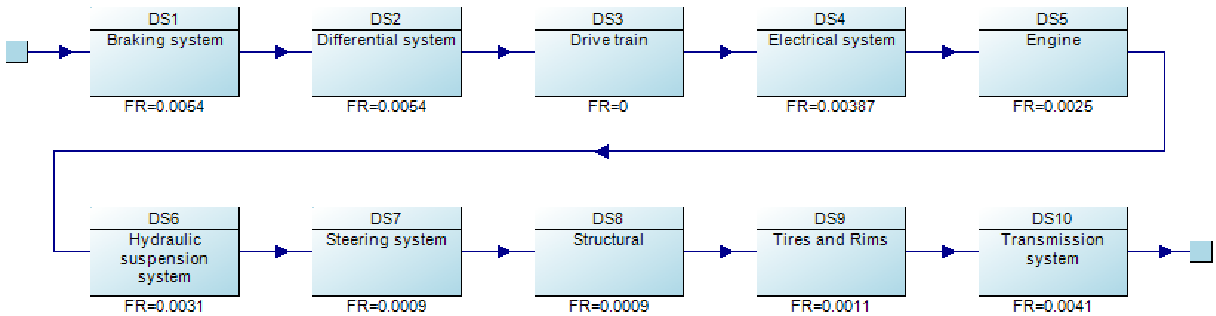


Figure 8.6 RBD of dumper – BD21

Table 8.1 Reliability of shovel and dumper using RBD

Surface coal mine										
Systems	KS1	KS2	BD3	BD4	BD5	BD6	KD7	KD8	KD9	KD10
R(t)	0.3103	0.3182	0.3044	0.2478	0.29	0.1866	0.3076	0.2701	0.3093	0.3265
F(t)	0.6897	0.6818	0.6956	0.7522	0.71	0.8134	0.6924	0.7299	0.6907	0.6735
Surface iron ore Mine										
System	KS11	KS12	BD13	BD14	BD15	KD16	KD17	KD18	-	-
R(t)	0.2652	0.2257	0.3487	0.3241	0.3292	0.3635	0.4156	0.3682	-	-
F(t)	0.7348	0.7743	0.6513	0.6759	0.6708	0.6365	0.5844	0.6318	-	-
Surface Limestone Mine										
System	KS19	KS20	BD21	BD22	BD23	KD24	KD25	KD26	-	-
R(t)	0.2696	0.3135	0.2558	0.3518	0.3396	0.3012	0.2563	0.2594	-	-
F(t)	0.7304	0.6865	0.7442	0.6482	0.6604	0.6988	0.7437	0.7406	-	-

8.1.2 Formulation of mathematical models

The mathematical models are formulated or developed based on the both Weibull parameters (i.e., η, β, γ) and failure rate for developed RBD's of both KS1 (Figure 8.1) and BD3 (Figure 8.2) for surface coal mine. The developed mathematical models are given by equation (8.1) and (8.2). Mathematical models for KS11, BD13 (for surface coal mine), KS19, BD21 (for surface limestone mine) are formulated or developed based on their Weibull parameters and failure rate and given as equation (8.3), (8.4), (8.5) and (8.6). Similarly, the mathematical models for KS2, BD4, BD5, BD6, KD7, KD8, KD9 and KD10 is developed and given in equation (8.7) to (8.26).

Using these obtained mathematical models or equations, reliability of all shovels and dumpers are calculated based on the Weibull parameters i.e., η, β, γ (refer Table 6.14) and failure rate (refer Table 5.5, 5.9 and 5.13) of each subsystem and given in Table 8.2. In Table 8.2, the reliability of the most of the subsystems is one because there is no failure. Still the reliability of each shovel and dumper are very less, because all subsystems are connected in series.

In the present section, mathematical models as a part of the research are developed for estimating reliability of each shovel and dumper systems, based on their subsystem (10 Nos.) failure rates. So one can use same models for estimating the reliability (shovel and dumpers) of irrespective of the no. of subsystems. One has to incorporate/ reduce the number of exceeding subsystems.

For KS1: Surface coal mine

$$R_{KS1}(t) = e^{-\left(\frac{t_{SS1}-\gamma 1}{\eta_{SS1}}\right)^{\beta_{SS1}}} \times e^{-\left(\frac{t_{SS2}-\gamma_{SS2}}{\eta_{SS2}}\right)^{\beta_{SS2}}} \times e^{-\left(\frac{t_{SS3}-\gamma_{SS3}}{\eta_{SS3}}\right)^{\beta_{SS3}}} \times e^{-\left(\frac{t_{SS4}-\gamma_{SS4}}{\eta_{SS4}}\right)^{\beta_{SS4}}}$$
$$\times e^{-\left(\frac{t_{SS5}-\gamma_{SS5}}{\eta_{SS5}}\right)^{\beta_{SS5}}} \times e^{-\left(\frac{t_{SS6}-\gamma_{SS6}}{\eta_{SS6}}\right)^{\beta_{SS6}}} \times e^{-\left(\frac{t_{SS7}-\gamma_{SS7}}{\eta_{SS7}}\right)^{\beta_{SS7}}} \times e^{-\left(\frac{t_{SS8}-\gamma_{SS8}}{\eta_{SS8}}\right)^{\beta_{SS8}}}$$
$$\times {}^{-\left(\frac{t_{SS9}-\gamma_{SS9}}{\eta_{SS9}}\right)^{\beta_{SS9}}} \times e^{-\left(\frac{t_{SS10}-\gamma_{SS10}}{\eta_{SS10}}\right)^{\beta_{SS10}}}$$

Since, $R_{SS1}=R_{SS4}=R_{SS8}=0$, because no failures in SS1, SS4 and SS8 of KS1

$$R_{KS1}(t) = R_{SS2}(t) \times R_{SS3}(t) \times R_{SS5}(t) \times R_{SS6}(t) \times R_{SS7}(t) \times R_{SS9}(t) \times R_{SS10}(t) \qquad (8.1)$$

For BD3: Surface coal mine

$$R_{BD3}(t) = e^{-\left(\frac{t_{DS1}-\gamma_{DS1}}{\eta_{DS1}}\right)^{\beta_{DS1}}} \times e^{-\left(\frac{t_{DS2}-\gamma_{DS2}}{\eta_{DS2}}\right)^{\beta_{DS2}}} \times e^{-\left(\frac{t_{DS3}-\gamma_{DS3}}{\eta_{DS3}}\right)^{\beta_{DS3}}} \times e^{-\left(\frac{t_{DS4}-\gamma_{DS4}}{\eta_{DS4}}\right)^{\beta_{DS4}}}$$
$$\times e^{-\left(\frac{t_{DS5}-\gamma_{DS5}}{\eta_{DS5}}\right)^{\beta_{DS5}}} \times e^{-\left(\frac{t_{DS6}-\gamma_{SS6}}{\eta_{DS6}}\right)^{\beta_{DS6}}} \times e^{-\left(\frac{t_{DS7}-\gamma_{DS7}}{\eta_{DS7}}\right)^{\beta_{DS7}}} \times e^{-\left(\frac{t_{DS8}-\gamma_{DS8}}{\eta_{DS8}}\right)^{\beta_{DS8}}}$$
$$\times e^{-\left(\frac{t_{DS9}-\gamma_{DS9}}{\eta_{DS9}}\right)^{\beta_{DS9}}} \times e^{-\left(\frac{t_{DS10}-\gamma_{DS10}}{\eta_{DS10}}\right)^{\beta_{DS10}}}$$

Since, $R_{DS3}=R_{DS8}=R_{DS9}=0$, because no failures in DS3, DS8 and DS9 of BD3

$$R_{BD3}(t) = R_{DS1}(t) \times R_{DS2}(t) \times R_{DS4}(t) \times R_{DS5}(t) \times R_{DS6}(t) \times R_{DS7}(t) \times R_{DS10}(t) \qquad (8.2)$$

For KS11: Surafce iron ore mine

$$R_{KS11}(t) = e^{-(\frac{t_{SS1}-\gamma 1}{\eta_{SS1}})^{\beta_{SS1}}} \times e^{-(\frac{t_{SS2}-\gamma_{SS2}}{\eta_{SS2}})^{\beta_{SS2}}} \times e^{-(\frac{t_{SS3}-\gamma_{SS3}}{\eta_{SS3}})^{\beta_{SS3}}} \times e^{-(\frac{t_{SS4}-\gamma_{SS4}}{\eta_{SS4}})^{\beta_{SS4}}}$$
$$\times e^{-(\frac{t_{SS5}-\gamma_{SS5}}{\eta_{SS5}})^{\beta_{SS5}}} \times e^{-(\frac{t_{SS6}-\gamma_{SS6}}{\eta_{SS6}})^{\beta_{SS6}}} \times e^{-(\frac{t_{SS7}-\gamma_{SS7}}{\eta_{SS7}})^{\beta_{SS7}}} \times e^{-(\frac{t_{SS8}-\gamma_{SS8}}{\eta_{SS8}})^{\beta_{SS8}}}$$
$$\times e^{-(\frac{t_{SS9}-\gamma_{SS9}}{\eta_{SS9}})^{\beta_{SS9}}} \times e^{-(\frac{t_{SS10}-\gamma_{SS10}}{\eta_{SS10}})^{\beta_{SS10}}}$$

Since, $R_{SS1}=R_{SS2}=R_{SS4}=R_{SS8}=R_{SS9}=0$, because no failures in SS1, SS2, SS4, SS8 and SS9 of KS11

$$R_{KS11}(t) = R_{SS3}(t) \times R_{SS5}(t) \times R_{SS6}(t) \times R_{SS7}(t) \times R_{SS10}(t) \tag{8.3}$$

For BD13: Surface iron ore mine

$$R_{BD13}(t) = e^{-(\frac{t_{DS1}-\gamma_{DS1}}{\eta_{DS1}})^{\beta_{DS1}}} \times e^{-(\frac{t_{DS2}-\gamma_{DS2}}{\eta_{DS2}})^{\beta_{DS2}}} \times e^{-(\frac{t_{DS3}-\gamma_{DS3}}{\eta_{DS3}})^{\beta_{DS3}}} \times e^{-(\frac{t_{DS4}-\gamma_{DS4}}{\eta_{DS4}})^{\beta_{DS4}}}$$
$$\times e^{-(\frac{t_{DS5}-\gamma_{DS5}}{\eta_{DS5}})^{\beta_{DS5}}} \times e^{-(\frac{t_{DS6}-\gamma_{SS6}}{\eta_{DS6}})^{\beta_{DS6}}} \times e^{-(\frac{t_{DS7}-\gamma_{DS7}}{\eta_{DS7}})^{\beta_{DS7}}} \times e^{-(\frac{t_{DS8}-\gamma_{DS8}}{\eta_{DS8}})^{\beta_{DS8}}}$$
$$\times e^{-(\frac{t_{DS9}-\gamma_{DS9}}{\eta_{DS9}})^{\beta_{DS9}}} \times e^{-(\frac{t_{DS10}-\gamma_{DS10}}{\eta_{DS10}})^{\beta_{DS10}}}$$

Since, $R_{DS2}=R_{DS10}=0$, because no failures in DS2 and DS10 of BD13

$$R_{BD13}(t) = R_{DS1}(t) \times R_{DS3}(t) \times R_{DS4}(t) \times R_{DS5}(t) \times R_{DS6}(t) \times R_{DS7}(t) \times R_{DS8}(t) \times R_{DS9}(t) \tag{8.4}$$

For KS19: Surface limestone mine

$$R_{KS19}(t) = e^{-(\frac{t_{SS1}-\gamma 1}{\eta_{SS1}})^{\beta_{SS1}}} \times e^{-(\frac{t_{SS2}-\gamma_{SS2}}{\eta_{SS2}})^{\beta_{SS2}}} \times e^{-(\frac{t_{SS3}-\gamma_{SS3}}{\eta_{SS3}})^{\beta_{SS3}}} \times e^{-(\frac{t_{SS4}-\gamma_{SS4}}{\eta_{SS4}})^{\beta_{SS4}}}$$
$$\times e^{-(\frac{t_{SS5}-\gamma_{SS5}}{\eta_{SS5}})^{\beta_{SS5}}} \times e^{-(\frac{t_{SS6}-\gamma_{SS6}}{\eta_{SS6}})^{\beta_{SS6}}} \times e^{-(\frac{t_{SS7}-\gamma_{SS7}}{\eta_{SS7}})^{\beta_{SS7}}} \times e^{-(\frac{t_{SS8}-\gamma_{SS8}}{\eta_{SS8}})^{\beta_{SS8}}}$$
$$\times e^{-(\frac{t_{SS9}-\gamma_{SS9}}{\eta_{SS9}})^{\beta_{SS9}}} \times e^{-(\frac{t_{SS10}-\gamma_{SS10}}{\eta_{SS10}})^{\beta_{SS10}}}$$

Since, $R_{SS8}=R_{SS10}=0$, because no failures in SS8 and SS10

$$R_{KS19}(t) = R_{SS1} \times R_{SS2} \times R_{SS3}(t) \times R_{SS5}(t) \times R_{SS6}(t) \times R_{SS7}(t) \times R_{SS9}(t) \tag{8.5}$$

For BD21: Surface limestone mine

$$R_{BD21}(t) = e^{-(\frac{t_{DS1}-\gamma_{DS1}}{\eta_{DS1}})^{\beta_{DS1}}} \times e^{-(\frac{t_{DS2}-\gamma_{DS2}}{\eta_{DS2}})^{\beta_{DS2}}} \times e^{-(\frac{t_{DS3}-\gamma_{DS3}}{\eta_{DS3}})^{\beta_{DS3}}} \times e^{-(\frac{t_{DS4}-\gamma_{DS4}}{\eta_{DS4}})^{\beta_{DS4}}} \times e^{-(\frac{t_{DS5}-\gamma_{DS5}}{\eta_{DS5}})^{\beta_{DS5}}} \times e^{-(\frac{t_{DS6}-\gamma_{SS6}}{\eta_{DS6}})^{\beta_{DS6}}} \times e^{-(\frac{t_{DS7}-\gamma_{DS7}}{\eta_{DS7}})^{\beta_{DS7}}} \times e^{-(\frac{t_{DS8}-\gamma_{DS8}}{\eta_{DS8}})^{\beta_{DS8}}} \times e^{-(\frac{t_{DS9}-\gamma_{DS9}}{\eta_{DS9}})^{\beta_{DS9}}} \times e^{-(\frac{t_{DS10}-\gamma_{DS10}}{\eta_{DS10}})^{\beta_{DS10}}}$$

Since, RDS3=0, because no failure in DS3 of BD21

$$R_{BD21}(t) = R_{DS1}(t) \times R_{DS2}(t) \times R_{DS4}(t) \times R_{DS5}(t) \times R_{DS6}(t) \times R_{DS7}(t) \times R_{DS8}(t) \times R_{DS9}(t) \times R_{DS10}(t) \qquad (8.6)$$

Similarly other shovels and dumpers from all three surface mines are

$$R_{KS2}(t) = R_{SS1}(t) \times R_{SS2}(t) \times R_{SS3}(t) \times R_{SS4}(t) \times R_{SS5}(t) \times R_{SS6}(t) \times R_{SS7}(t) \times R_{SS8}(t) \times R_{SS9}(t) \times R_{SS10}(t) \qquad (8.7)$$

Since, R_{SS3}=R_{SS4}= R_{SS8}=0

$$R_{BD4}(t) = R_{DS1}(t) \times R_{DS2}(t) \times R_{DS4}(t) \times R_{DS5}(t) \times R_{DS6}(t) \times R_{DS7}(t) \times R_{DS8}(t) \times R_{DS9}(t) \times R_{DS10}(t) \qquad (8.8)$$

Since, R_{DS3}=R_{DS8}= R_{DS9}=0

$$R_{BD5}(t) = R_{DS1}(t) \times R_{DS2}(t) \times R_{DS4}(t) \times R_{DS5}(t) \times R_{DS6}(t) \times R_{DS7}(t) \times R_{DS8}(t) \times R_{DS9}(t) \times R_{DS10}(t) \qquad (8.9)$$

Since, R_{DS1}=R_{DS83}= R_{DS9}=0

$$R_{BD6}(t) = R_{DS1}(t) \times R_{DS2}(t) \times R_{DS4}(t) \times R_{DS5}(t) \times R_{DS6}(t) \times R_{DS7}(t) \times R_{DS8}(t) \times R_{DS9}(t) \times R_{DS10}(t) \qquad (8.10)$$

Since, R_{DS3}=R_{DS7}=R_{DS8}=R_{DS9}=0

$$R_{KD7}(t) = R_{DS1}(t) \times R_{DS2}(t) \times R_{DS4}(t) \times R_{DS5}(t) \times R_{DS6}(t) \times R_{DS7}(t) \times R_{DS8}(t) \times R_{DS9}(t) \times R_{DS10}(t) \qquad (8.11)$$

Since, R_{DS3}=0

$$R_{KD8}(t) = R_{DS1}(t) \times R_{DS2}(t) \times R_{DS4}(t) \times R_{DS5}(t) \times R_{DS6}(t) \times R_{DS7}(t) \times R_{DS8}(t) \times R_{DS9}(t) \times R_{DS10}(t) \qquad (8.12)$$

Since, R_{DS3}=R_{DS7}=0

$$R_{KD9}(t) = R_{DS1}(t) \times R_{DS2}(t) \times R_{DS4}(t) \times R_{DS5}(t) \times R_{DS6}(t) \times R_{DS7}(t) \times R_{DS8}(t) \times R_{DS9}(t) \times R_{DS10}(t) \qquad (8.13)$$

Since, R_{DS3}=0

$$R_{KD10}(t) = R_{DS1}(t) \times R_{DS2}(t) \times R_{DS4}(t) \times R_{DS5}(t) \times R_{DS6}(t) \times R_{DS7}(t) \times R_{DS8}(t) \times R_{DS9}(t) \times R_{DS10}(t) \qquad (8.14)$$

Since, $R_{DS1}=R_{DS3}= 0$

$$R_{KS12}(t) = R_{SS1}(t)\times R_{SS2}(t)\times R_{SS3}(t)\times R_{SS4}(t)\times R_{SS5}(t)\times R_{SS6}(t)\times R_{SS7}(t)\times R_{SS8}(t)\times R_{SS9}(t)\times R_{SS10}(t) \quad (8.15)$$

Since, $R_{SS1}=R_{SS2}=R_{SS3}=R_{SS4}=R_{SS8}= 0$

$$R_{BD14}(t) = R_{DS1}(t)\times R_{DS2}(t)\times R_{DS4}(t)\times R_{DS5}(t)\times R_{DS6}(t)\times R_{DS7}(t)\times R_{DS8}(t)\times R_{DS9}(t)\times R_{DS10}(t) \quad (8.16)$$

Since, $R_{SS2}=R_{SS10}=0$

$$R_{BD15}(t) = R_{DS1}(t)\times R_{DS2}(t)\times R_{DS4}(t)\times R_{DS5}(t)\times R_{DS6}(t)\times R_{DS7}(t)\times R_{DS8}(t)\times R_{DS9}(t)\times R_{DS10}(t) \quad (8.17)$$

Since, $R_{SS9}=R_{SS10}=0$

$$R_{KD16}(t) = R_{DS1}(t)\times R_{DS2}(t)\times R_{DS4}(t)\times R_{DS5}(t)\times R_{DS6}(t)\times R_{DS7}(t)\times R_{DS8}(t)\times R_{DS9}(t)\times R_{DS10}(t) \quad (8.18)$$

Since, $R_{SS1}=R_{SS10}=0$

$$R_{KD17}(t) = R_{DS1}(t)\times R_{DS2}(t)\times R_{DS4}(t)\times R_{DS5}(t)\times R_{DS6}(t)\times R_{DS7}(t)\times R_{DS8}(t)\times R_{DS9}(t)\times R_{DS10}(t) \quad (8.19)$$

Since, $R_{DS10}=0$

$$R_{KD18}(t) = R_{DS1}(t)\times R_{DS2}(t)\times R_{DS4}(t)\times R_{DS5}(t)\times R_{DS6}(t)\times R_{DS7}(t)\times R_{DS8}(t)\times R_{DS9}(t)\times R_{DS10}(t) \quad (8.20)$$

Since, $R_{DS7}=R_{DS10}=0$

$$R_{KS20}(t) = R_{SS1}(t)\times R_{SS2}(t)\times R_{SS3}(t)\times R_{SS4}(t)\times R_{SS5}(t)\times R_{SS6}(t)\times R_{SS7}(t)\times R_{SS8}(t)\times R_{SS9}(t)\times R_{SS10}(t) \quad (8.21)$$

Since, $R_{SS8}=0$

$$R_{BD22}(t) = R_{DS1}(t)\times R_{DS2}(t)\times R_{DS3}(t)\times R_{DS4}(t)\times R_{DS5}(t)\times R_{DS6}(t)\times R_{DS7}(t)\times R_{DS8}(t)\times R_{DS9}(t)\times R_{DS10}(t) \quad (8.22)$$

$$R_{BD23}(t) = R_{DS1}(t)\times R_{DS2}(t)\times R_{DS4}(t)\times R_{DS5}(t)\times R_{DS6}(t)\times R_{DS7}(t)\times R_{DS8}(t)\times R_{DS9}(t)\times R_{DS10}(t) \quad (8.23)$$

Since, $R_{DS7}=0$

$$R_{KD24}(t) = R_{DS1}(t)\times R_{DS2}(t)\times R_{DS4}(t)\times R_{DS5}(t)\times R_{DS6}(t)\times R_{DS7}(t)\times R_{DS8}(t)\times R_{DS9}(t)\times R_{DS10}(t) \quad (8.24)$$

Since, $R_{DS7}=0$

$$R_{KD25}(t) = R_{DS1}(t)\times R_{DS2}(t)\times R_{DS4}(t)\times R_{DS5}(t)\times R_{DS6}(t)\times R_{DS7}(t)\times R_{DS8}(t)\times R_{DS9}(t)\times R_{DS10}(t) \quad (8.25)$$

Since, $R_{DS3}=R_{DS7}=0$

$$R_{KD26}(t) = R_{DS1}(t)\times R_{DS2}(t)\times R_{DS4}(t)\times R_{DS5}(t)\times R_{DS6}(t)\times R_{DS7}(t)\times R_{DS8}(t)\times R_{DS9}(t)\times R_{DS10}(t) \quad (8.26)$$

Since, $R_{DS3}=R_{DS7}=0$

Table 8.2 Reliability of each subsystem and overall reliability of the system

Surface Coal Mine		$R_{SS1}(t)$	$R_{SS2}(t)$	$R_{SS3}(t)$	$R_{SS4}(t)$	$R_{SS5}(t)$	$R_{SS6}(t)$	$R_{SS7}(t)$	$R_{SS8}(t)$	$R_{SS9}(t)$	$R_{SS10}(t)$	$R(t)$
	KS1	1	0.974	0.799	1	0.682	0.856	0.769	1	0.929	0.974	0.317
	KS2	1.	0.951	0.860	1	0.774	0.831	0.718	1	0.904	0.918	0.315
		$R_{DS1}(t)$	$R_{DS2}(t)$	$R_{DS3}(t)$	$R_{DS4}(t)$	$R_{DS5}(t)$	$R_{DS6}(t)$	$R_{DS7}(t)$	$R_{DS8}(t)$	$R_{DS9}(t)$	$R_{DS10}(t)$	$R(t)$
	BD3	0.838	0.936	1	0.811	0.793	0.734	0.886	1	1	0.925	0.304
	BD4	0.825	0.784	1	0.784	0.868	0.804	0.794	1	1	0.868	0.244
	BD5	1.000	0.788	1	0.927	0.818	0.893	0.927	0.927	1	0.637	0.293
	BD6	0.771	0.878	1	0.833	0.435	0.833	1	1	1	0.901	0.184
	KD7	0.927	0.909	1	0.683	0.884	0.896	0.953	0.821	0.927	0.909	0.302
	KD8	0.934	0.949	1	0.755	0.883	0.723	1	0.852	0.890	0.835	0.271
	KD9	0.936	0.970	1	0.622	0.876	0.919	0.947	0.830	0.860	0.976	0.301
	KD10	1.000	0.912	1	0.990	0.731	0.794	0.855	0.920	0.903	0.879	0.328
Surface Iron Ore Mine		$R_{SS1}(t)$	$R_{SS2}(t)$	$R_{SS3}(t)$	$R_{SS4}(t)$	$R_{SS5}(t)$	$R_{SS6}(t)$	$R_{SS7}(t)$	$R_{SS8}(t)$	$R_{SS9}(t)$	$R_{SS10}(t)$	$R(t)$
	KS11	1	1	0.750	1	0.884	0.630	0.784	1	1	0.829	0.272
	KS12	1		1	1	0.791	0.435	0.785	1	0.820	1	0.222
		$R_{DS1}(t)$	$R_{DS2}(t)$	$R_{DS3}(t)$	$R_{DS4}(t)$	$R_{DS5}(t)$	$R_{DS6}(t)$	$R_{DS7}(t)$	$R_{DS8}(t)$	$R_{DS9}(t)$	$R_{DS10}(t)$	$R_{DS1}(t)$
	BD13	0.955	1	0.957	0.932	0.915	0.871	0.874	0.597	0.979	1	0.348
	BD14	0.745	1	0.931	0.857	0.859	0.911	0.929	0.765	0.975	1	0.323
	BD15	0.962	0.4595	0.978	0.925	0.942	0.971	0.978	0.917	1.000	1	0.329
	KD16	1	0.997	0.999	0.999	0.997	0.997	0.999	0.998	0.367	1	0.363
	KD17	0.651	0.882	0.985	0.995	0.988	0.996	0.829	0.993	0.908	1	0.415
	KD18	0.982	0.988	0.414	0.973	0.988	0.979	1	0.970	0.992	1	0.365
Surface Limestone Mine		$R_{SS1}(t)$	$R_{SS2}(t)$	$R_{SS3}(t)$	$R_{SS4}(t)$	$R_{SS5}(t)$	$R_{SS6}(t)$	$R_{SS7}(t)$	$R_{SS8}(t)$	$R_{SS9}(t)$	$R_{SS10}(t)$	$R(t)$
	KS19	0.8930	0.8373	0.8019	0.8258	0.7923	0.9359	0.7498	1.0000	0.966	1	0.266
	KS20	0.9133	0.9397	0.9034	0.8140	0.8905	0.8633	0.7858	1.0000	0.907	0.901	0.312
		$R_{DS1}(t)$	$R_{DS2}(t)$	$R_{DS3}(t)$	$R_{DS4}(t)$	$R_{DS5}(t)$	$R_{DS6}(t)$	$R_{DS7}(t)$	$R_{DS8}(t)$	$R_{DS9}(t)$	$R_{DS10}(t)$	$R(t)$
	BD21	0.763	0.763	1	0.824	0.882	0.856	0.956	0.956	0.946	0.814	0.255
	BD22	0.949	0.949	0.949	0.812	0.855	0.949	0.949	0.901	0.949	0.771	0.353
	BD23	0.923	0.960	0.960	0.886	0.886	0.960	1	0.960	0.786	0.697	0.339
	KD24	0.923	0.886	1	0.571	0.923	0.886	1	0.923	0.923	0.923	0.301
	KD25	0.923	0.852	1	0.670	0.786	0.786	1	0.923	0.923	0.923	0.256
	KD26	0.963	0.910	1	0.625	0.910	0.910	1	0.828	0.828	0.828	0.258

8.1.3 Fussell-Vesely Importance

The Fussell-Vesely measures are used to calculate for consequence frequencies and risk categories. The Fussell-Vesely standard importance measure indicates each subsystem contribution to the system reliability/unreliability or availability/unavailability (for RBDs) or failure frequency for consequences or risk for risk categories. Increasing the reliability/availability of subsystem with high importance values will have the most significant effect on system availability, consequence frequency or risk. The standard Fussell-Vesely unavailability importance value for a component is given by equation (8.27).

$$I_i^{FV} = \frac{F(t)_{System} - F(t)_{System}(q_i = 0)}{F(t)_{System}} \tag{8.27}$$

Where, I_i^{FV} - Fussel-Vesely Importance for subsystem i

$F(t)_{System}$ - Probability, consequence frequency of risk

$F(t)_{System}(q_i=0)$ - System probability, consequence frequency or risk with the probability of component i set to 0

Fussell-Vesely Importance graphs is observed that estimate the influencing failure parts (i.e., failure rate: λ) of the system towards performance drop of the following systems: (i) shovel (KS1 and KS2) and dumpers (BD3, BD4, BD5, BD6, KD7, KD8, KD9 and KD10) in surface coal mine, (ii) shovel (KS11, KS12) and dumpers (BD13, BD14, BD15, KD16, KD17 and KD18 in surface iron ore mine, (iii) shovel (KS19, KS20) and dumpers (BD21, BD22, BD22, KD24, KD25 and KD26 in surface limestone mine. Here, only one shovel and one dumper is taken from each mine for explanation purpose and details of remaining shovels and dumpers are given in Section D.2, Annexure-D.

Figure 8.7 shows the Fussel-Vesely Importance of KS1 as per their breakdown, hours. In and provides to estimate the failure rate (λ)of the system towards performance drop of the KS1. In Fussel-Vesely Importance of KS1 (Figure 8.10), it is found that SS5 is more affected on dropping the performance due to its failure rate. Similarly, BD3 found DS2 (Figure 8.8), KS11 found SS6 (Figure 8.9), BD13 found DS8 (Figure 8.10), KS19 found SS7 (Figure 8.11) and BD21 found DS1 (Figure 8.12) is more affected on dropping the performance due to its failure rate.

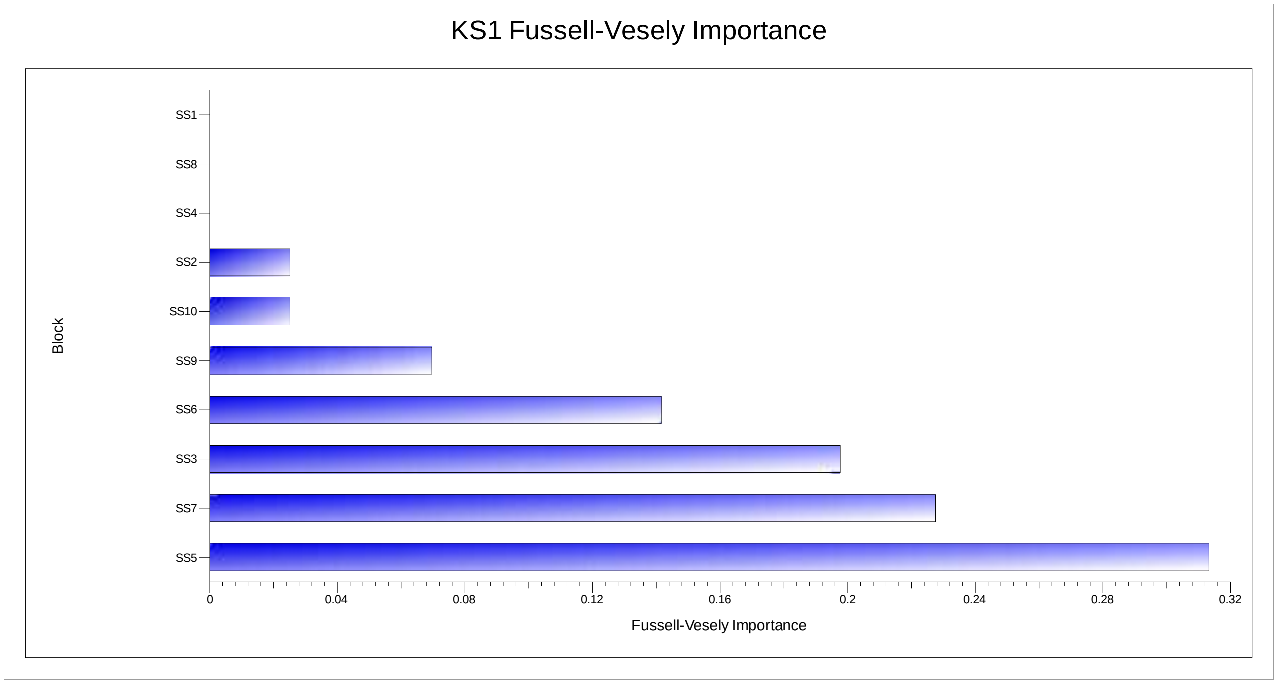


Figure 8.7 Fussell-Vesely Importance of KS1 (surface coal mine)

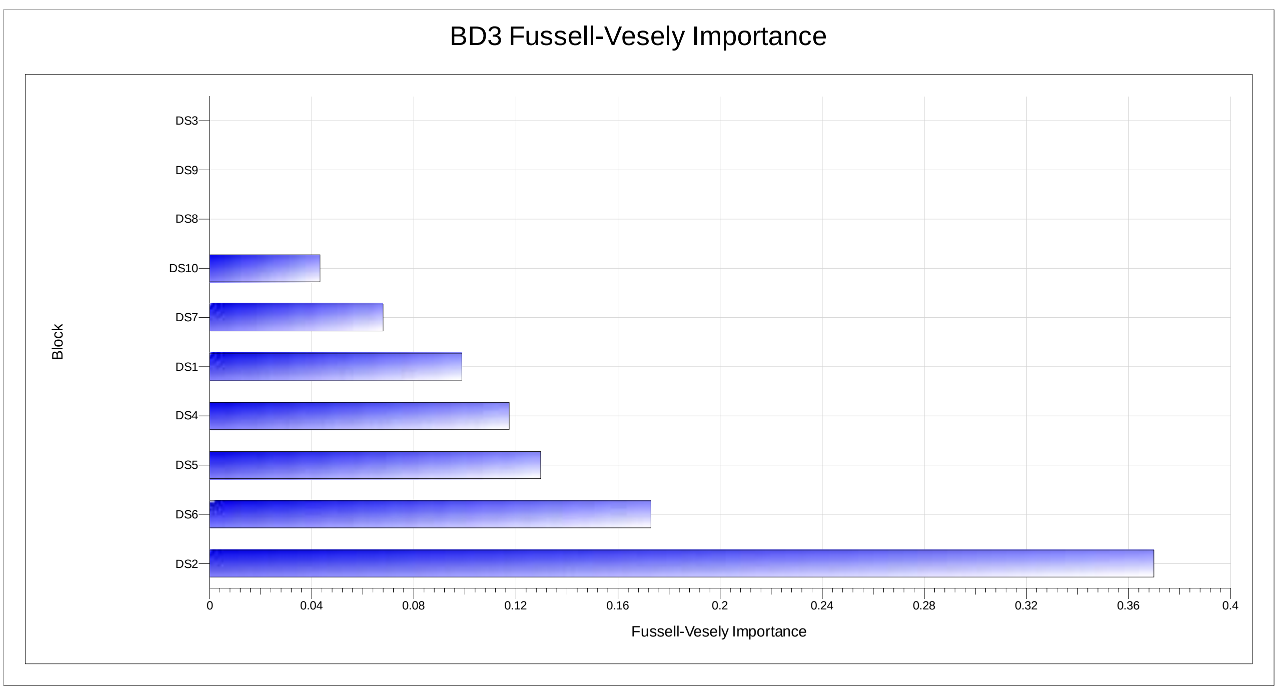


Figure 8.8 Fussell-Vesely Importance of BD3 (surface coal mine)

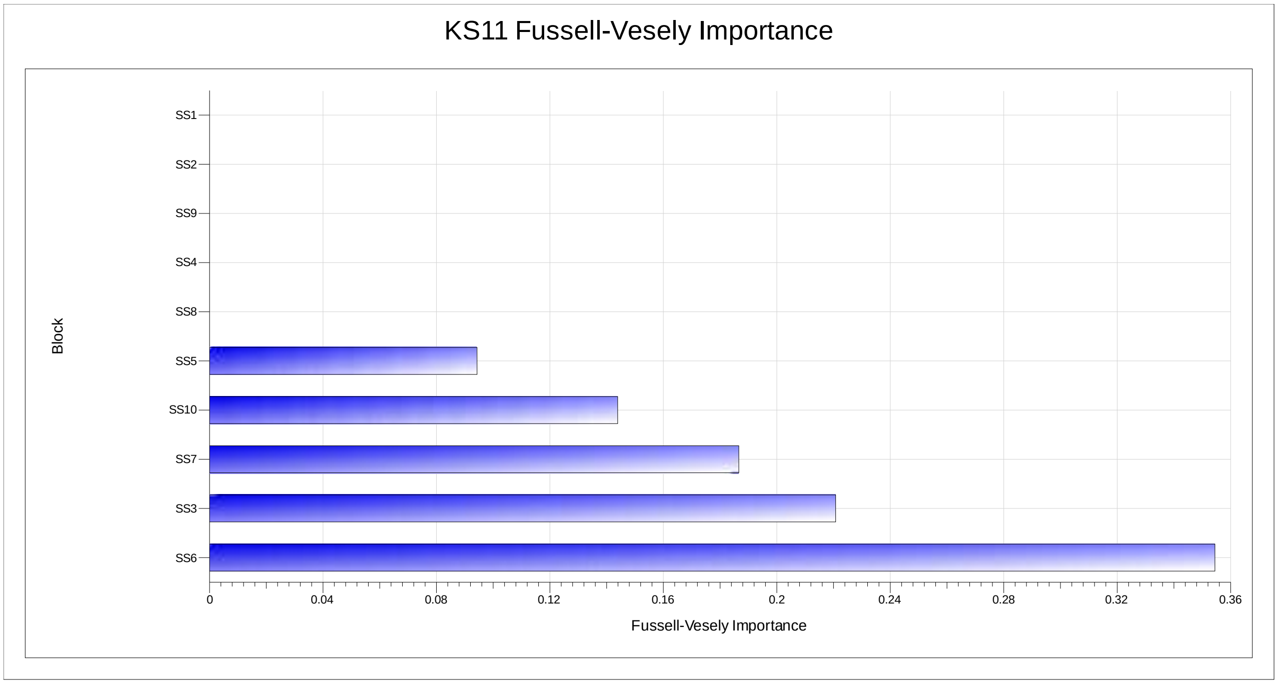


Figure 8.9 Fussell-Vesely Importance of KS11 (surface iron ore mine)

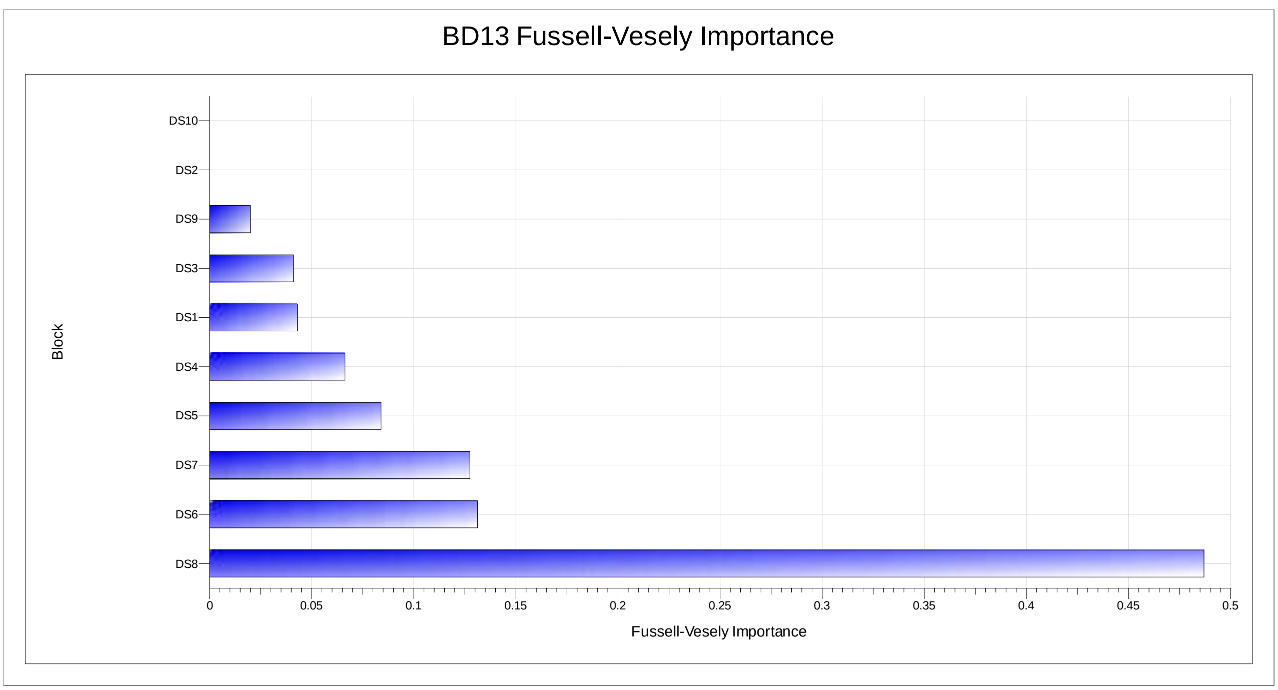


Figure 8.10 Fussell-Vesely Importance of BD13 (surface iron ore mine)

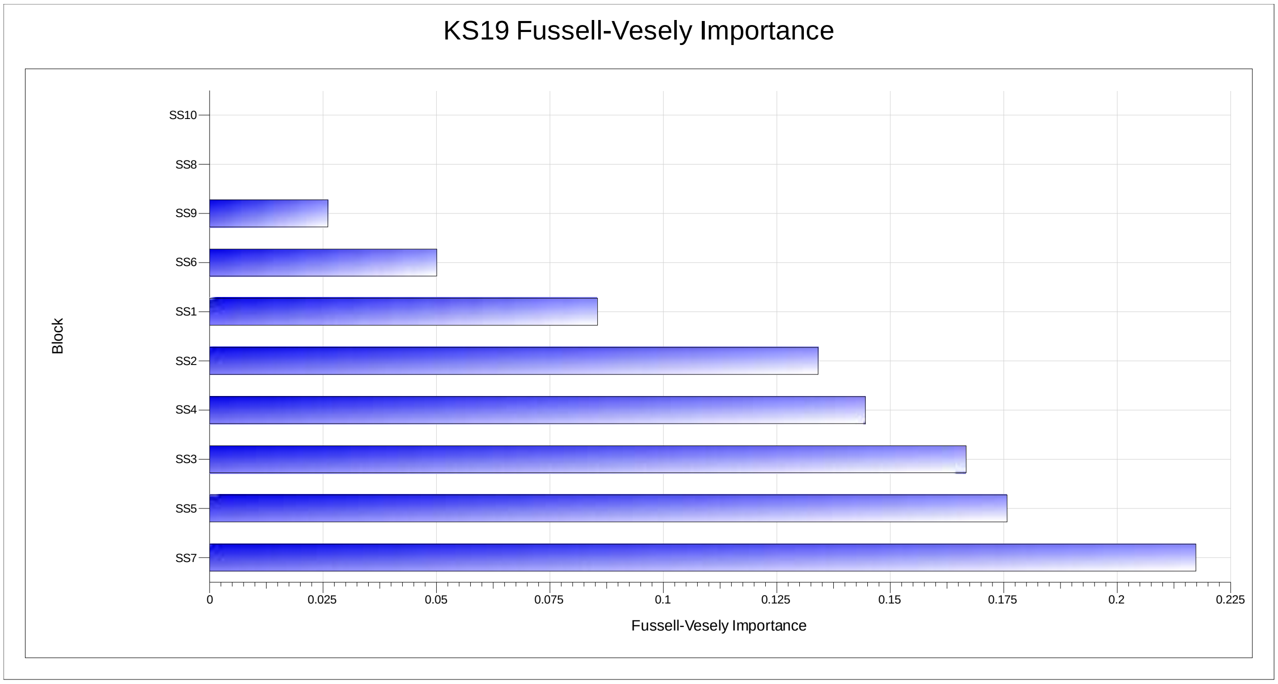


Figure 8.11 Fussell-Vesely Importance of KS19 (surface limestone mine)

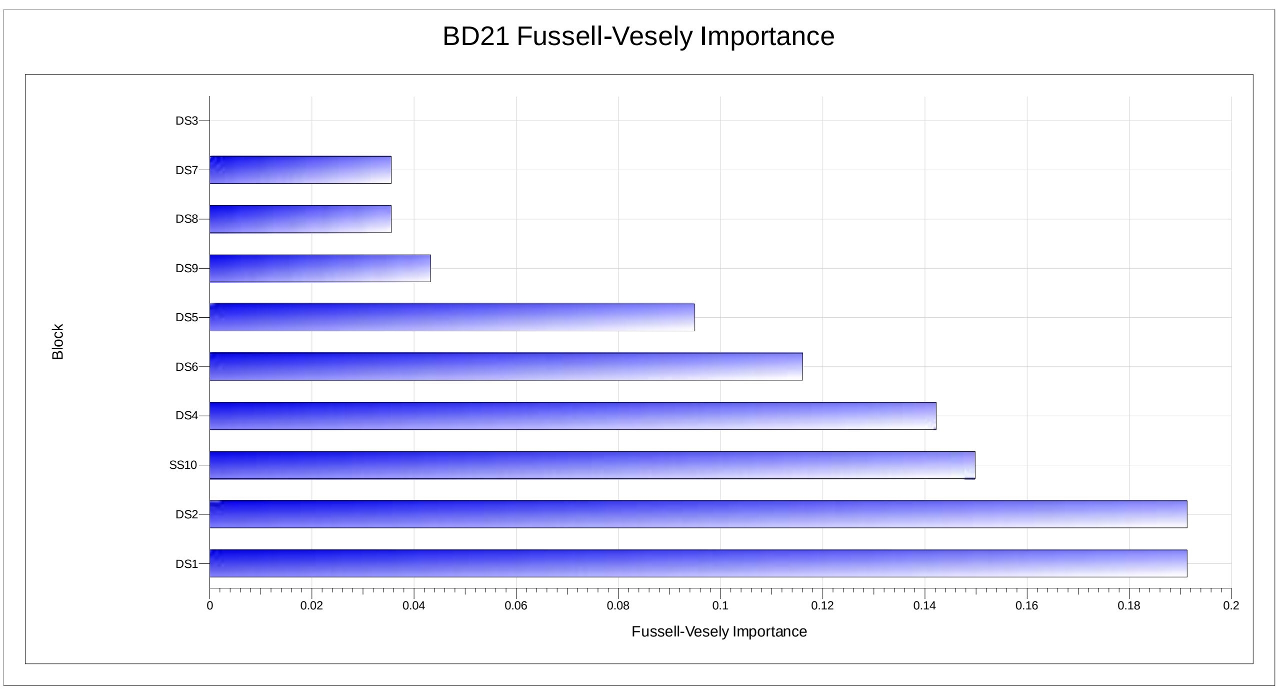


Figure 8.12 Fussell-Vesely Importance of BD21 as per breakdown hours

8.1.4 Series-Parallel configuration

Surface coal mine: The series-parallel configuration is a combination of series and parallel in a system (a combination of shovel and dumper). In this configuration, there are two groups are made such as group 1 i.e., G1 (G1 it includes KS1, BD3, BD4, KD7 and KD8) and group 2 i.e., G2 (G2 included KS2, BD5, BD6, KD9 and KD10) based on the best fit distribution. In group 1 (G1), shovel KS1 works parallel to the dumpers BD3, BD4, KD7 and KD8 and all these dumpers such as BD3, BD4, KD7 and KD8 are works in a series configuration. Similarly, in group 2 (G2), shovel KS2 works parallel to the dumpers BD5, BD6, KD9 and KD10 and all these dumpers such as BD5, BD6, KD9 and KD10 are works in a series configuration. The series-parallel configuration of the shovel-dumper systems (i.e., G1and G2) are showed in Figure 8.13 and 8.14. The numerically, G1 and G2 are the best possible configuration of the components for improving reliability of the shovel-dumper system.

The RBD of the series-parallel configuration of shovel and dumper is constructed using Isograph Reliability Workbench. However, the reliability of G1 and G2 are predicted using Isograph Reliability Workbench and shown in Figure 8.15 and 8.16 and also predicated improved reliability is given in Table 8.3. In table 8.3 observe that, the reliability of the shovel-dumper system has improved in the RBD of series-parallel configuration i.e., 0.7034 and 0.7374 and behavior of reliability measures has been observed graphically as shown in Figure 8.17. Also, mathematical models were developed for the designed RBD of series-parallel configuration (for Figure 8.13 and 8.14) and given in equation (8.28) and (8.29).

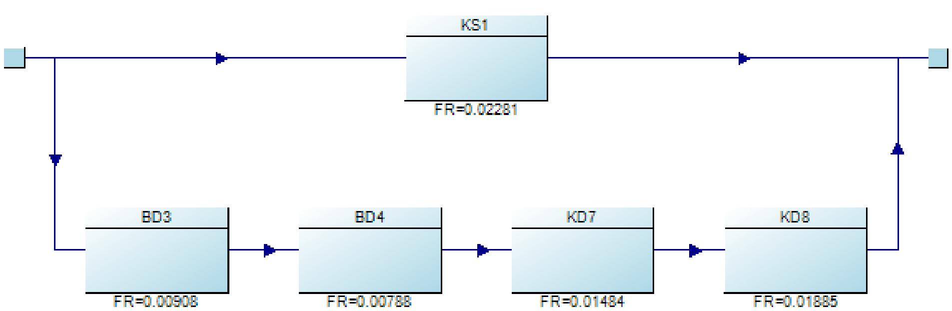


Figure 8.13 RBD of shovel-dumper system in surface coal mine (G1)

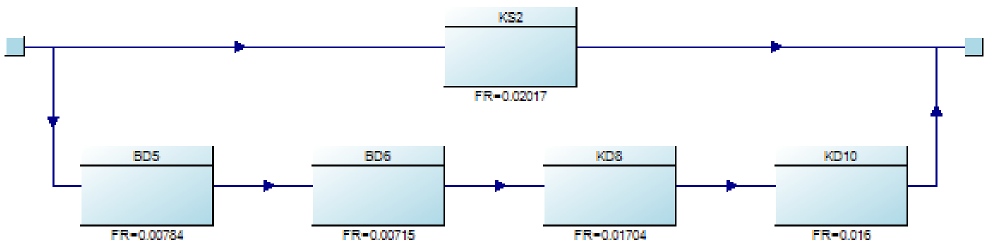


Figure 8.14 RBD of shovel-dumper system in surface coal mine (G2)

For G1 (KS1, BD3, BD4, KD7, KD8): Surface coal mine

$$R_{G1} = 1-[1-e^{-[\frac{t_{KS1}-\gamma_{KS1}}{\eta_{KS1}}]^{\beta_{KS1}}}][1-(e^{-[\frac{t_{BD1}-\gamma_{BD1}}{\eta_{BD1}}]^{\beta_{BD1}}} * e^{-[\frac{t_{BD2}-\gamma_{BD2}}{\eta_{BD2}}]^{\beta_{BD2}}} * e^{-[\frac{t_{KD5}-\gamma_{KD5}}{\eta_{KD5}}]^{\beta_{KD5}}} * e^{-[\frac{t_{KD6}-\gamma_{KD6}}{\eta_{KD6}}]^{\beta_{KD6}}})] \tag{8.28}$$

For G2 (KS2, BD5, BD6, KD9, KD10): Surface coal mine

$$R_{G2} = 1-[1-e^{-[\frac{t_{KS2}-\gamma_{KS2}}{\eta_{KS2}}]^{\beta_{KS2}}}][1-(e^{-[\frac{t_{BD3}-\gamma_{BD3}}{\eta_{BD3}}]^{\beta_{BD3}}} * e^{-[\frac{t_{BD4}-\gamma_{BD4}}{\eta_{BD4}}]^{\beta_{BD4}}} * e^{-[\frac{t_{KD7}-\gamma_{KD7}}{\eta_{KD7}}]^{\beta_{KD7}}} * e^{-[\frac{t_{KD8}-\gamma_{KD8}}{\eta_{KD8}}]^{\beta_{KD8}}})] \tag{8.29}$$

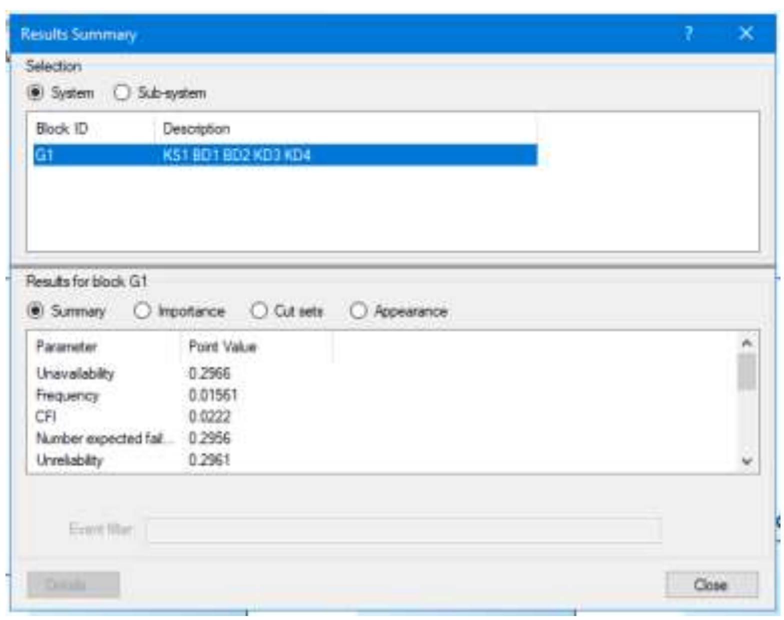


Figure 8.15 Result summary of G1 Surface coal mine

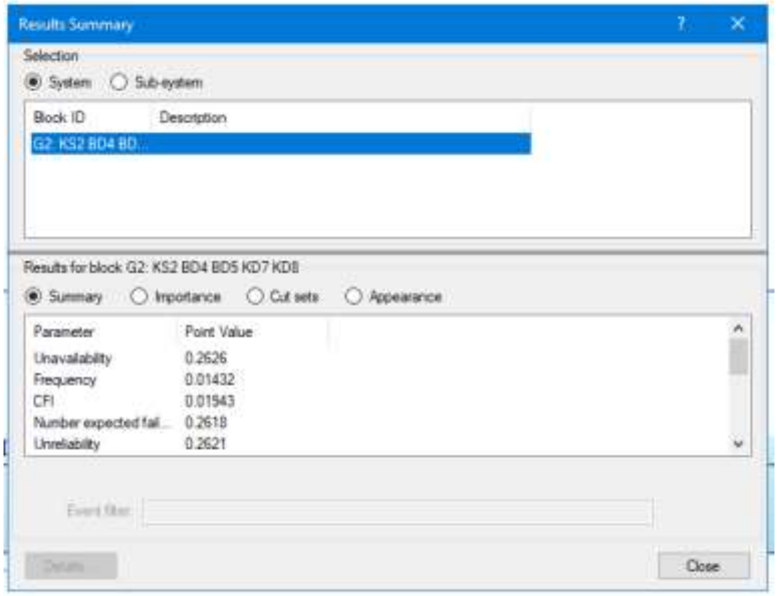


Figure 8.16 Result summary of G2 surface coal mine

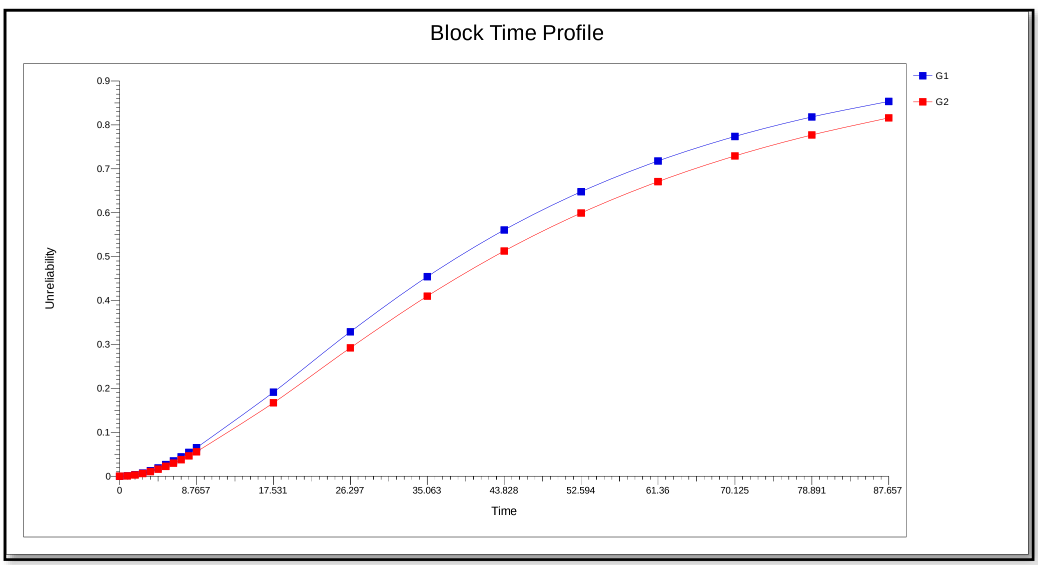


Figure 8.17 Unreliability of combined a shovel and dumpers in the parallel network (G1 & G2) in surface coal mine

Surface iron ore mine: The series-parallel configuration is a combination of series and parallel in a system (a combination of shovel and dumper). In this configuration, there are two groups are made such as group 1 i.e., G1 (G1 it includes KS11, BD13, BD14 and BD15) and group 2 i.e., G2 (G2 included KS12, KD16, KD17 and KD18) based on the best fit distribution. In group 1 (G1), shovel KS11 works parallel to the dumpers BD13, BD14 and

BD15 and all these dumpers such as BD13, BD14 and KD15 are works in a series configuration. Similarly, in group 2 (G2), shovel KS12 works parallel to the dumpers KD16, KD17 and KD18 and all these dumpers such as KD16, KD17 and KD18 are works in a series configuration. The series-parallel configuration of the shovel-dumper systems (i.e., G1and G2) are showed in Figure 8.18 and 8.19. The numerically, G1 and G2 are the best possible configuration of the components for improving reliability of the shovel-dumper system.

The RBD of the series-parallel configuration of shovel and dumper is constructed using Isograph Reliability Workbench. However, the reliability of G1 and G2 are predicted using Isograph Reliability Workbench and shown in Figure 8.20 and 8.21 and also predicated improved reliability is given in Table 8.3. In Table 8.3 we observed that, the reliability of the shovel-dumper system has improved in the RBD of series-parallel configuration i.e., 0.5853 and 0.6 and behavior of reliability measures has been observed graphically as shown in Figure 8.22. Also, mathematical models were developed for the designed RBD of series-parallel configuration (for Figure 8.21 and 8.22) and given in equation (8.30) and (8.31).

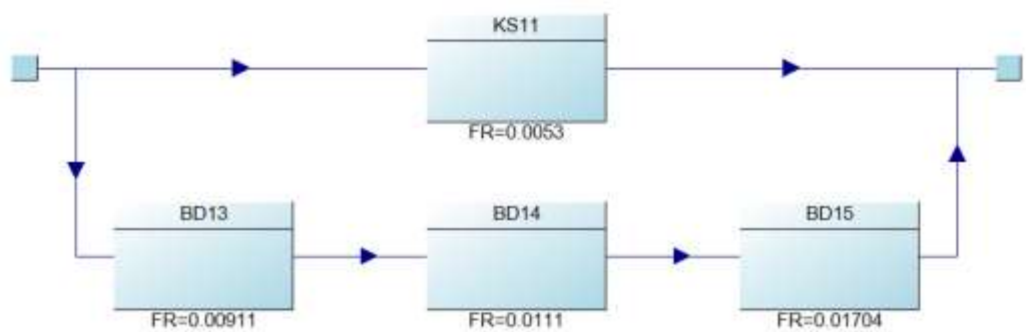


Figure 8.18 RBD of shovel-dumper system in iron ore mine (G1)

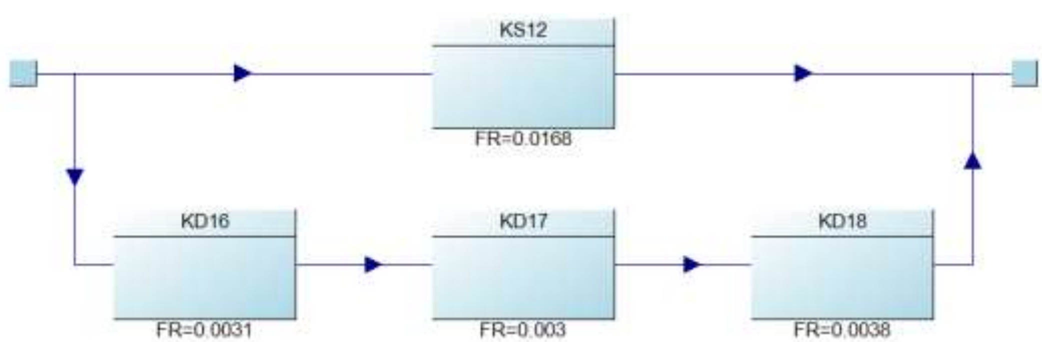


Figure 8.19 RBD of shovel-dumper system in iron ore mine (G2)

For G1 (KS11, BD13, BD14, BD15): Surface iron ore mine

$$R_{G1} = 1-[1-e^{-[\frac{t_{KS1}-\gamma_{KS1}}{\eta_{KS1}}]^{\beta_{KS1}}}][1-(e^{-[\frac{t_{BD1}-\gamma_{BD1}}{\eta_{BD1}}]^{\beta_{BD1}}} * e^{-[\frac{t_{BD2}-\gamma_{BD2}}{\eta_{BD2}}]^{\beta_{BD2}}} * e^{-[\frac{t_{KD5}-\gamma_{KD5}}{\eta_{KD5}}]^{\beta_{KD5}}} * e^{-[\frac{t_{KD6}-\gamma_{KD6}}{\eta_{KD6}}]^{\beta_{KD6}}})]$$

(8.30)

For G1 (KS12, KD16, KD17, KD18): Surface iron ore mine

$$R_{G2} = 1-[1-e^{-[\frac{t_{KS2}-\gamma_{KS2}}{\eta_{KS2}}]^{\beta_{KS2}}}][1-(e^{-[\frac{t_{BD3}-\gamma_{BD3}}{\eta_{BD3}}]^{\beta_{BD3}}} * e^{-[\frac{t_{BD4}-\gamma_{BD4}}{\eta_{BD4}}]^{\beta_{BD4}}} * e^{-[\frac{t_{KD7}-\gamma_{KD7}}{\eta_{KD7}}]^{\beta_{KD7}}} * e^{-[\frac{t_{KD8}-\gamma_{KD8}}{\eta_{KD8}}]^{\beta_{KD8}}})]$$

(8.31)

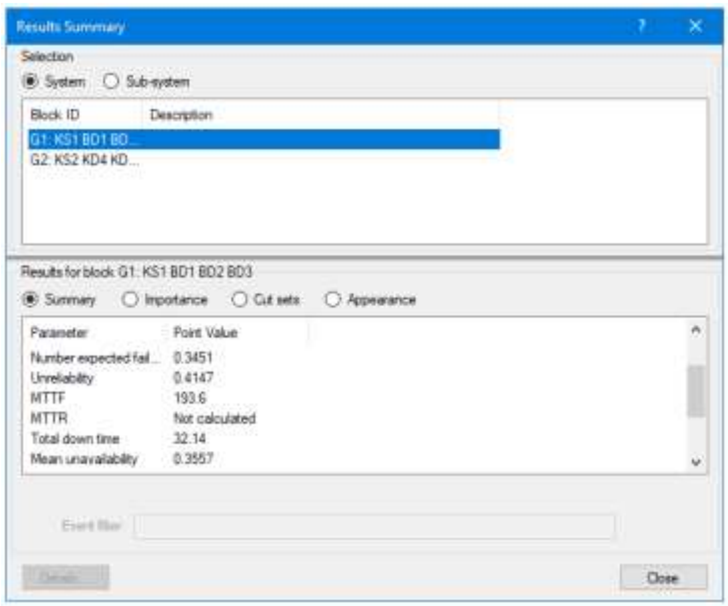


Figure 8.20 Result summary of G1in surface iron ore mine

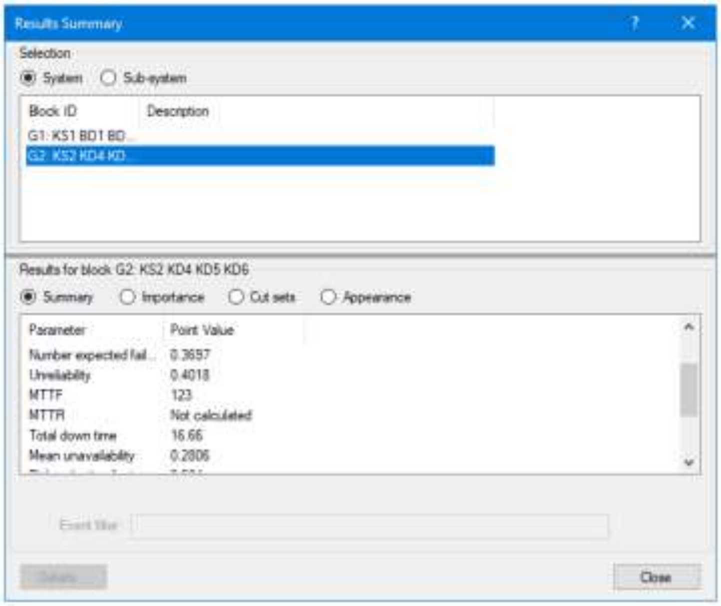


Figure 8.21 Result summary of G2 in surface iron ore mine

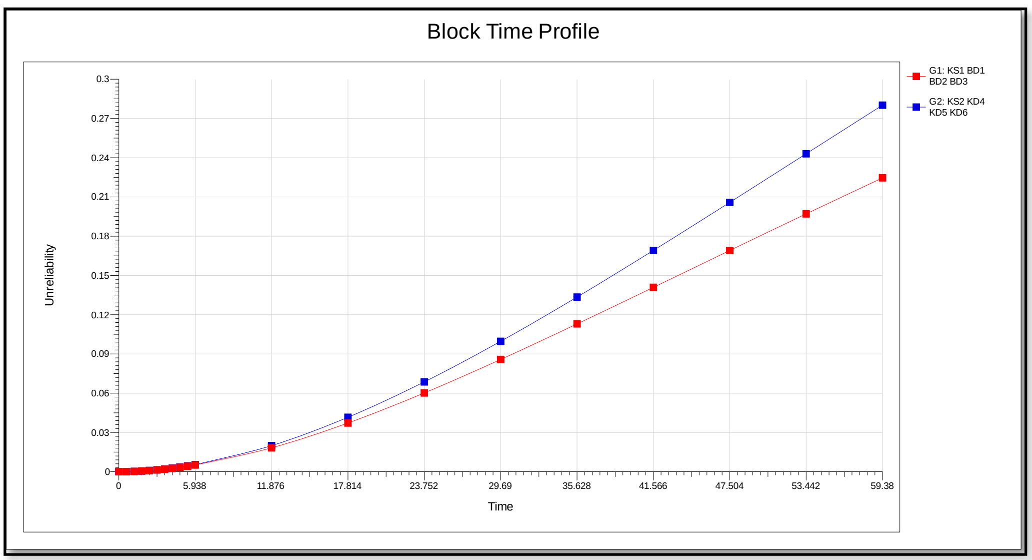


Figure 8.22 Unreliability of combined a shovel and dumpers in the parallel network (G1 & G2) in iron ore mine

Surface limestone mine: The series-parallel configuration is a combination of series and parallel in a system (a combination of shovel and dumper). In this configuration, there are two groups are made such as group 1 i.e., G1 (G1 it includes KS19, BD21, BD22 and BD23) and group 2 i.e., G2 (G2 included KS20, KD24, KD25 and KD26) based on the best fit distribution. In group 1 (G1), shovel KS19 works parallel to the dumpers BD21, BD22 and BD23 and all these dumpers such as BD21, BD22 and BD23 are works in a series configuration. Similarly, in group 2 (G2), shovel KS20 works parallel to the dumpers KD24, KD25 and KD26 and all these dumpers such as KD24, KD25 and KD26 are works in a series configuration. The series-parallel configuration of the shovel-dumper systems (i.e., G1and G2) are showed in Figure 8.23 and 8.24. The numerically, G1 and G2 are the best possible configuration of the components for improving reliability of the shovel-dumper system.

The RBD of the series-parallel configuration of shovel and dumper is constructed using Isograph Reliability Workbench. However, the reliability of G1 and G2 are predicted using Isograph Reliability Workbench and shown in Figure 8.25 and 8.26 and also predicated improved reliability is given in Table 8.3. Table 8.3 observed that, the reliability of the shovel-dumper system has improved in the RBD of series-parallel configuration i.e., 0.497 and 0.521 and behavior of reliability measures has been observed graphically as shown in Figure 8.27. Also, mathematical models were developed for the designed RBD of series-parallel configuration (for Figure 8.26 and 8.27) and given in equation (8.32) and (8.33).

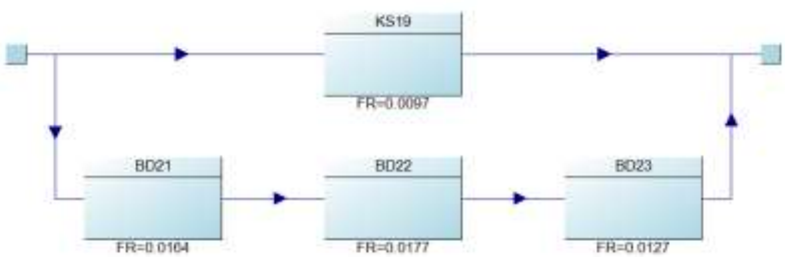


Figure 8.23 RBD of shovel-dumper system in limestone mine (G1)

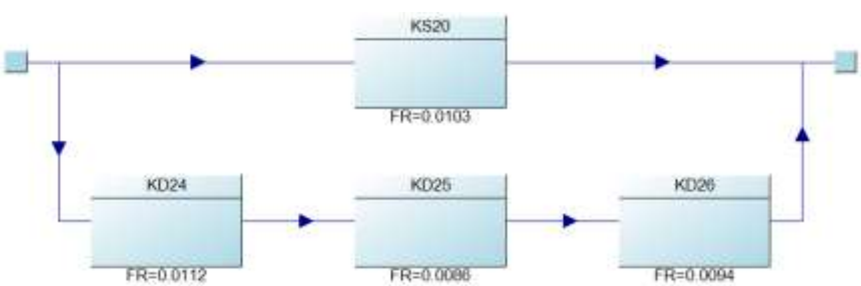


Figure 8.24 RBD of shovel-dumper system in limestone mine (G2)

For G1 (KS19, BD20, BD21, BD22): Surface limestone mine

$$R_{G1} = 1-[1-e^{-[\frac{t_{KS1}-\gamma_{KS1}}{\eta_{KS1}}]^{\beta_{KS1}}}][1-(e^{-[\frac{t_{BD1}-\gamma_{BD1}}{\eta_{BD1}}]^{\beta_{BD1}}} * e^{-[\frac{t_{BD2}-\gamma_{BD2}}{\eta_{BD2}}]^{\beta_{BD2}}} * e^{-[\frac{t_{KD5}-\gamma_{KD5}}{\eta_{KD5}}]^{\beta_{KD5}}} * e^{-[\frac{t_{KD6}-\gamma_{KD6}}{\eta_{KD6}}]^{\beta_{KD6}}})] \quad (8.32)$$

For G1 (KS20, KD24, KD25, KD26): Surface limestone mine

$$R_{G2} = 1 - [1 - e^{-[\frac{t_{KS2}-\gamma_{KS2}}{\eta_{KS2}}]^{\beta_{KS2}}}][1 - (e^{-[\frac{t_{BD3}-\gamma_{BD3}}{\eta_{BD3}}]^{\beta_{BD3}}} * e^{-[\frac{t_{BD4}-\gamma_{BD4}}{\eta_{BD4}}]^{\beta_{BD4}}} * e^{-[\frac{t_{KD7}-\gamma_{KD7}}{\eta_{KD7}}]^{\beta_{KD7}}} * e^{-[\frac{t_{KD8}-\gamma_{KD8}}{\eta_{KD8}}]^{\beta_{KD8}}})] \tag{8.33}$$

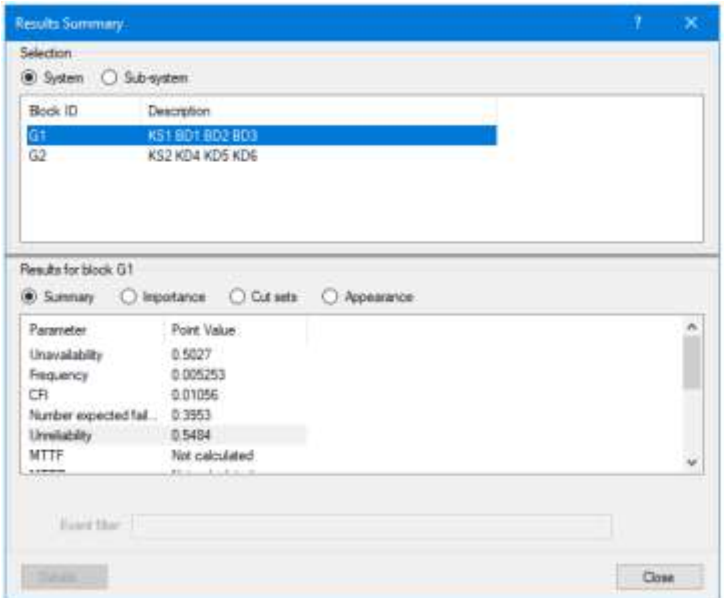


Figure 8.25 Result summary of G1 in limestone mine

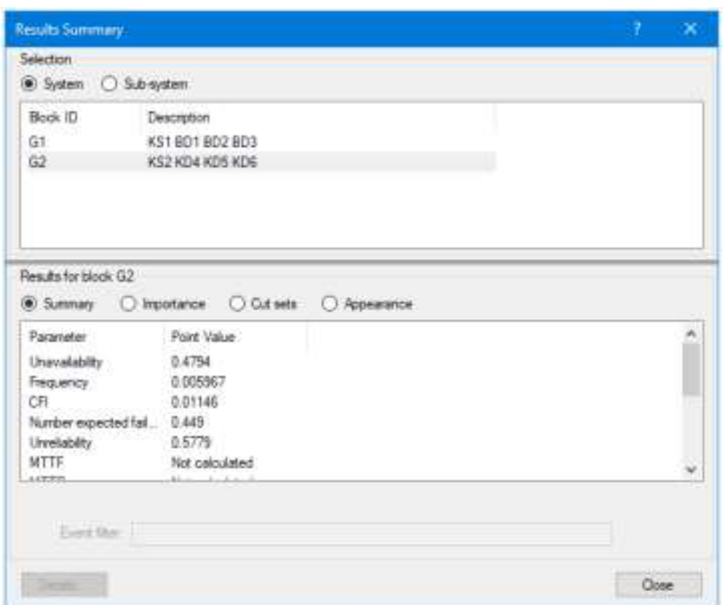


Figure 8.26 Result summary of G2 in limestone mine

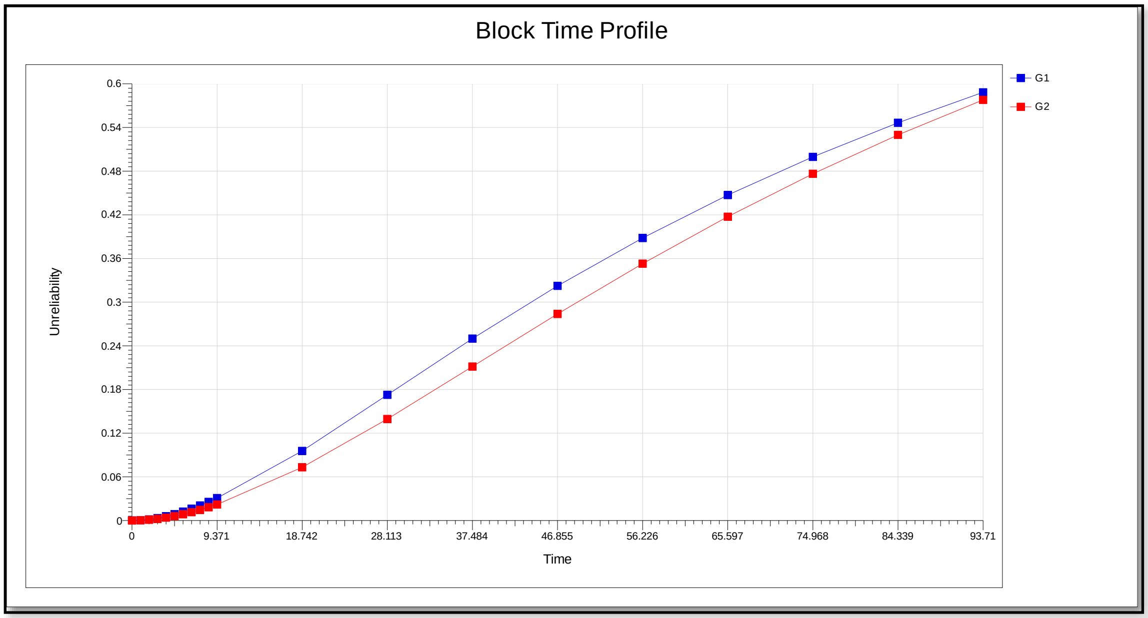


Figure 8.27 Unreliability of combined a shovel and dumpers in the parallel network (G1 & G2) in limestone mine

Table 8.3 Reliability improvement in series-parallel configuration

	Surface coal mine		**Surface iron ore mine**		**Surface limestone mine**	
RBD combination	G1	G2	G1	G2	G1	G2
Reliability	0.7034	0.737	0.5853	0.6	0.497	0.521

CHAPTER 9

MARKOV MODEL

9.1 Markov Modeling of Shovel-Dumper System in Coal, Iron Ore and Limestone Mine

A Markov model is an easily formulated, graphically assisted and mathematically tractable probability model that can account for simultaneously-active event processes of a system in a continuous-time, homogeneous Markov chain. The Markov approach can be applied to the random behavior of systems or subsystems failure such as failures of shovels and dumpers in the surface mines that vary discretely or continuously corresponds to time i.e., failure and repair time, characterized by future states has been independent of all past states, except the directly previous one.

Reliability modeling of a repairable subsystems via the state space method employs a set of states, each one corresponding to a specific condition of the system such as, subsystem SS1 in shovel is failed", "loss of redundancy," "repair in progress," and "system failed." Then, the probability model specifies the likelihood of each state being entered according to the time and the allocation of the waiting time in the state at the entrance. The sum of these probabilities must be unified and the system can be in one state under consideration or moved to another. A tree diagram can illustrate the behavior of this system.

As time increases, the values of state probabilities tend to a constant or limiting value. These values are known as limiting-state or time-independent values of the state probabilities and are one of the most significant results of the reliability analysis. In this analysis, Markov model and mathematical formulation have been developed for each shovel and dumper during working hours in the each surface mine. The system consists of ten dissimilar subsystems arranging in series and there is no standby. A reliability block diagram of a series system with 10 components as shown in Chapter 8 (Figure 8.1, 8.2, 8.3, 8.4, 8.5 and 8.6), admitting only that the system is working or not, this system has 11 states (i.e., Number of states = Number of subsystems (10+1 = 11 states).

In transition diagram (Figure 9.1 and 9.2), all 10 subsystems are working properly i.e., working state (WS), so that system is in a fully working condition and other states are failure states (FS). All possible working state and failure states of systems are tabulated in Table 9.1 and same for all three mines of shovel and dumper. For example, if SS1 failed and other 9 subsystems are working it can be called as FS (Failed states), its results whole system (either shovel or dumper) will be failed condition because all subsystems are connected in series. The detailed analysis of Markov model of each mine has discussed further.

Table 9.1 Relevance of ten components with eleven states

Sl. No	State	State of subsystem	State system	Probability being state
1	S_0	No Failure	Working State (WS)	$P_0(t)$
2	S_1	SS1/DS1 Failed	Failure State (FS)	$P_1(t)$
3	S_2	SS2/DS2 Failed	Failure State (FS)	$P_2(t)$
4	S_3	SS3/DS3 Failed	Failure State (FS)	$P_3(t)$
5	S_4	SS4/DS4 Failed	Failure State (FS)	$P_4(t)$
6	S_5	SS5/DS5 Failed	Failure State (FS)	$P_5(t)$
7	S_6	SS6/DS6 Failed	Failure State (FS)	$P_6(t)$
8	S_7	SS7/DS7 Failed	Failure State (FS)	$P_7(t)$
9	S_8	SS8/DS8 Failed	Failure State (FS)	$P_8(t)$
10	S_9	SS9/DS9 Failed	Failure State (FS)	$P_9(t)$
11	S_{10}	SS10/DS10 Failed	Failure State (FS)	$P_{10}(t)$
Where, S_0 – Working condition at 0^{th} state, S_1 – Failure condition at 1^{st} state, S_2 - Failure condition at 2^{nd} state, $P_0(t)$ – Probability of state 0, $P_1(t)$ – Probability of state 1				

In surface coal mine, the MTBF's and MTTR's of the individual subsystems of shovel (KS1 and KS2) and dumpers (BD3, BD4, BD5, BD6, KD7, KD8, KD9 and KD10) are given in Table 5.5 (Chapter 5), whereas the periodic inspection intervals are t=10 hours to t=100 hours, all of which are orders of magnitude smaller than the MTBF's and MTTR's. The repairable systems of shovel which consists of ten subsystems namely SS1, SS2, SS3, SS4, SS5, SS6, SS7, SS8, SS9 and SS10 in are series. Similarly, the repairable system of dumper which consists of ten subsystems namely DS1, DS2, DS3, DS4, DS5, DS6, DS7, DS8, DS9 and DS10 are in series.

Also, most of the states being repaired with constant failure rate and repair rate of each subsystem (SS1, SS2, SS3, SS4, SS5, SS6, SS7, SS8, SS9 and SS10 for shovels and DS1, DS2, DS3, DS4, DS5, DS6, DS7, DS8, DS9 and DS10 for dumpers) of shovel and dumper are given by λ = 1/MTBF and μ=1/MTTR respectively. Here, only one shovel and one dumper were considered from each mine.

The Markov model has been constructed for the overall system of shovels (i.e., KS1 from surface coal mine, KS11 from surface iron ore mine and KS19 from surface limestone mine) and dumpers (i.e., BD3 from surface coal mine, BD13 from surface iron ore mine and BD21 from surface limestone mine) as shown below as state transition diagrams or Markov model. The state transition diagrams of KS1, KS11 and KS19 as shown in Figure 9.1, 9.2 and 9.3 and these Markov models are developed based on the RBD of KS1 (refer Figure 8.1), KS12 (refer Figure 8.3) and KS19 (refer Figure 8.5) with repair rate. Details of other Markov model of shovels and dumper are given in Section D.3, Annexure–D.

In Figure 9.1 (For KS1), state S_0 is good working condition and other state such as S_2 (SS2), S_3 (SS3), S_5 (SS5), S_6 (SS6), S_7 (SS7), S_9 (SS9) and S_{10} (SS10) are failed state due to failure of any one or more subsystems in shovel KS1. The mathematical model were developed for KS1 and given as equation (9.9). With the help of supplementary variable technique reliability measures of the system have been evaluated:

(i) Transition state probabilities of the each shovel and dumper system in surface coal mine.

(ii) A series of measures of reliability of each shovel and dumper system using failure rate and repair rate.

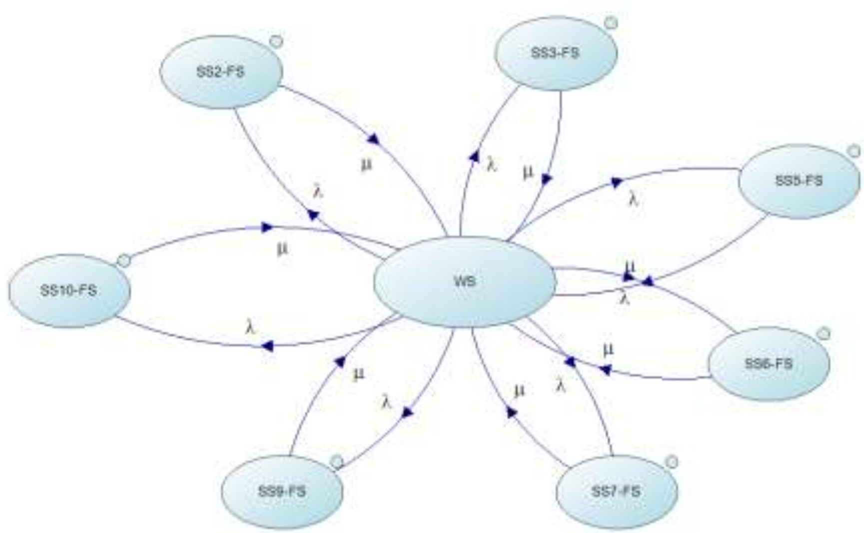


Figure 9.1 Transition diagram of KS1

Formulation of mathematical model for shovel KS1 (for surface coal mine) using Markov model of KS1 (Figure 9.1), following equations has been generated

$$\frac{dP_0}{dt} = -\lambda_2 P_0 - \lambda_3 P_0 - \lambda_5 P_0 - \lambda_6 P_0 - \lambda_7 P_0 - \lambda_9 P_0 - \lambda_{10} P_0 + \mu_2 P_2 + \mu_3 P_3 + \mu_5 P_5 + \mu_6 P_6 + \mu_7 P_7 + \mu_9 P_9 + \mu_{10} P_{10}$$

(9.1)

$$\frac{dP_0}{dt} = -P_0(\lambda_2 + \lambda_3 + \lambda_5 + \lambda_6 + \lambda_7 + \lambda_9 + \lambda_{10}) + \mu_2 P_2 + \mu_3 P_3 + \mu_5 P_5 + \mu_6 P_6 + \mu_7 P_7 + \mu_9 P_9 + \mu_{10} P_{10}$$

(9.2)

$$\frac{dP_0}{dt} = -P_0 \sum_{i=1}^{7} \lambda_i + \mu_2 P_2 + \mu_3 P_3 + \mu_5 P_5 + \mu_6 P_6 + \mu_7 P_7 + \mu_9 P_9 + \mu_{10} P_{10}$$

(9.3)

$$[\frac{d}{dt} + \sum_{i=1}^{7} \lambda_i]P_0 = \mu_2 P_2 + \mu_3 P_3 + \mu_5 P_5 + \mu_6 P_6 + \mu_7 P_7 + \mu_9 P_9 + \mu_{10} P_{10}$$

(9.4)

$$[\frac{d}{dt} + \alpha_m]P_i(t) = \beta_m P_j(t),$$
$$m = 1,2,2,3......,\ j = 0,1.2,3....,i = 1\, to\, 7$$

(9.5)

With initial condition

$$P_i(t) = 1 \text{ when i} = 0 \text{ and } P_i = 0 \text{ when i} > 0$$

(9.6)

In this steady state, the derivative of the state probabilities in equation 9.1 to 9.5 are set to zero and solving the resulting equations recursively and obtained the following steady-state probabilities:

P_2=X_2P_0 P_3=X_3P_0 P_5=X_5P_0 P_6=X_6P_0

P_7=X_7P_0 P_8=X_8P_0 P_{10}=$X_{10}P_0$

Probability of full working state (WS) P_0 is determined by using normalizing condition below

P_o+ P_2+ P_3+ P_5+ P_6+ P_7+ P_9+ P_{10}=1 (9.7)

Substituting the values of P_1 to P_7 in terms of P_0 into the normalizing condition in equation (9.7)

P_0(1+X_2+ X_{3+} X_{5+} X_{6+} X_7+ X_{9+} X_{10})=1 (9.8)

$$P_0 \times d_0 = 1$$

$$P_0 = \frac{1}{d_0} \tag{9.9}$$

where, $X_2 = \frac{\lambda_2}{\mu_2}, X_3 = \frac{\lambda_3}{\mu_3}, X_5 = \frac{\lambda_5}{\mu_5}, X_6 = \frac{\lambda_6}{\mu_6}, X_7 = \frac{\lambda_7}{\mu_7}, X_9 = \frac{\lambda_9}{\mu_9}, X_{10} = \frac{\lambda_{10}}{\mu_{10}}$

$$d_0 = 1 + X_2 + X_3 + X_5 + X_6 + X_7 + X_9 + X_{10}$$

In Figure 9.2 (For KS11 from surface iron ore mine), state S_0 is good working condition and other stats such as S_3 (SS3), S_5 (SS5), S_6 (SS6), S_7 (SS7) and S_{10} (SS10) are failed state due to failure of any one or more subsystems in shovel KS11. The mathematical model were developed for KS11 and given as equation (9.18). With the help of supplementary variable technique reliability measures of the system have been evaluated:

(i) Transition state probabilities of the each shovel and dumper system in iron ore mine.

(ii) A series of measures of reliability of each shovel and dumper system using failure rate and repair rate.

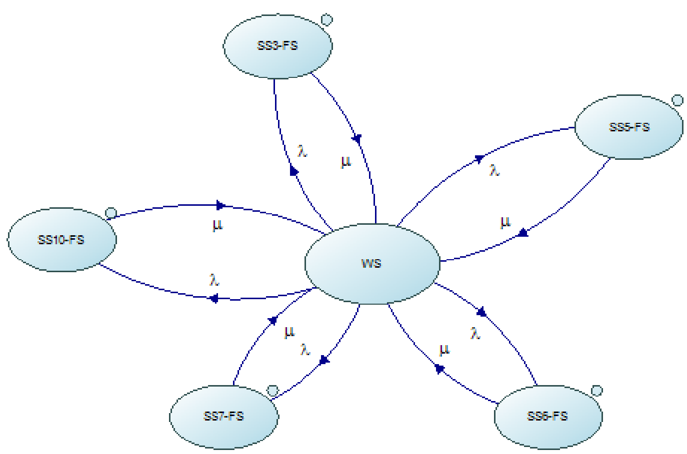


Figure 9.2 Transition diagram of KS11

Formulation of mathematical model for shovel KS11 (from surface iron ore mine) using Markov model of KS1 (Figure 9.2), following equations has been generated:

$$\frac{dP_0}{dt} = -\lambda_3 P_0 - \lambda_5 P_0 - \lambda_6 P_0 - \lambda_7 P_0 - \lambda_{10} P_{10} + \mu_3 P_3 + \mu_5 P_5 + \mu_6 P_6 + \mu_7 P_7 + \mu_{10} P_{10} \tag{9.10}$$

$$\frac{dP_0}{dt} = -P_0(\lambda_3 + \lambda_5 + \lambda_6 + \lambda_7 + \lambda_{10}) + \mu_3 P_3 + \mu_5 P_5 + \mu_6 P_6 + \mu_7 P_7 + \mu_{10} P_{10} \quad (9.11)$$

$$\frac{dP_0}{dt} = -P_0 \sum_{i=1}^{7} \lambda_i + \mu_3 P_3 + \mu_5 P_5 + \mu_6 P_6 + \mu_7 P_7 + \mu_{10} P_{10} \quad (9.12)$$

$$[\frac{d}{dt} + \sum_{i=1}^{7} \lambda_i] P_0 = \mu_3 P_3 + \mu_5 P_5 + \mu_6 P_6 + \mu_7 P_7 + \mu_{10} P_{10} \quad (9.13)$$

$$[\frac{d}{dt} + \alpha_m] P_i(t) = \beta_m P_j(t), \quad m = 1,2,2,3......, \; j = 0,1.2,3...., i = 1\, to\, 7 \quad (9.14)$$

With initial condition

$$P_i(t) = 1 \text{ when i} = 0 \text{ and } P_i = 0 \text{ when i} > 0 \quad (9.15)$$

In this steady state, the derivative of the state probabilities in equation 9.10 to 9.14 are set to zero and solving the resulting equations recursively and obtained the following steady-state probabilities:

$P_3=X_3P_0 \quad P_5=X_5P_0 \quad P_6=X_6P_0 \quad P_7=X_7P_0 \quad P_{10}=X_{10}P_0$

Probability of full working state (WS) P_0 is determined by using normalizing condition below

$$P_o+ P_3+ P_5+ P_6+ P_7+ P_{10}=1 \quad (9.16)$$

Substituting the values of P_1 to P_7 in terms of P_0 into the normalizing condition in equation (9.16)

$$P_0(1+X_{3+} X_{5+} X_{6+} X_7+X_{10})=1 \quad (9.17)$$

$$P_0 \times d_0 = 1$$

$$P_0 = \frac{1}{d_0} \quad (9.18)$$

$$\text{where, } X_3 = \frac{\lambda_3}{\mu_3}, X_5 = \frac{\lambda_5}{\mu_5}, X_6 = \frac{\lambda_6}{\mu_6}, X_7 = \frac{\lambda_7}{\mu_7}, X_{10} = \frac{\lambda_{10}}{\mu_{10}}$$

$$d_0 = 1 + X_3 + X_5 + X_6 + X_7 + X_{10}$$

In Figure 9.2 (For KS19), state S_0 is good working condition and other stats such as S_1 (SS1), S_2 (SS2), S_3 (SS3), S_4 (SS4), S_5 (SS5), S_6 (SS6), S_7 (SS7), and S_9 (SS9) are failed state due to failure of any one or more subsystems in shovel KS19. The mathematical model were developed for KS19 and given as equation (9.27). With the help of supplementary variable technique reliability measures of the system have been evaluated:

(i) Transition state probabilities of the each shovel and dumper system in surface limestone mine.

(ii) A series of measures of reliability of each shovel and dumper system using failure rate and repair rate.

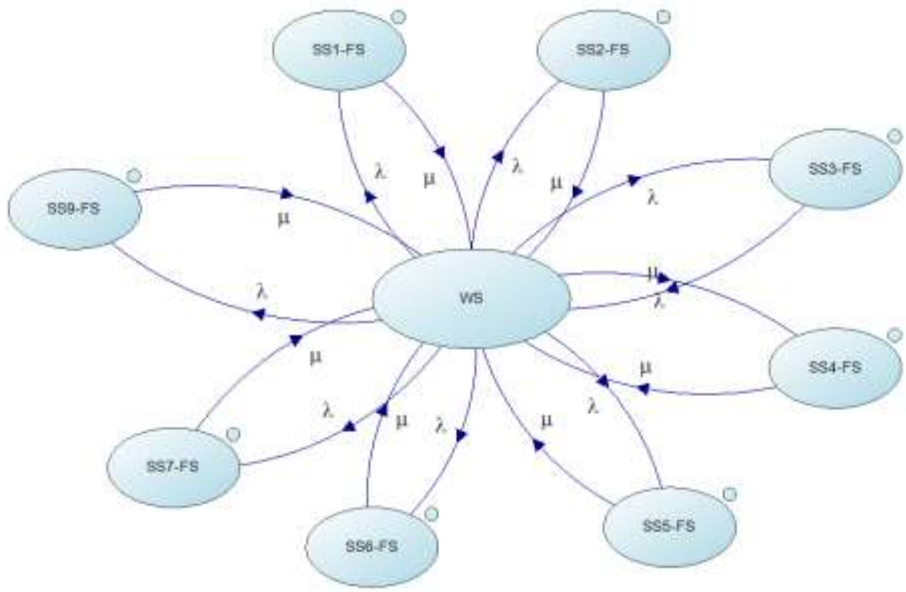


Figure 9.3 Transition diagram of KS19

Formulation of mathematical model for shovel KS19 (from surface limestone mine) using Markov model of KS19 (Figure 9.3), following equations has been generated:

$$\frac{dP_0}{dt} = -\lambda_3 P_0 - \lambda_5 P_0 - \lambda_6 P_0 - \lambda_7 P_0 - \lambda_{10} P_{10} + \mu_3 P_3 + \mu_5 P_5 + \mu_6 P_6 + \mu_7 P_7 + \mu_{10} P_{10} \quad (9.19)$$

$$\frac{dP_0}{dt} = -P_0(\lambda_3 + \lambda_5 + \lambda_6 + \lambda_7 + \lambda_{10}) + \mu_3 P_3 + \mu_5 P_5 + \mu_6 P_6 + \mu_7 P_7 + \mu_{10} P_{10} \quad (9.20)$$

$$\frac{dP_0}{dt} = -P_0 \sum_{i=1}^{7} \lambda_i + \mu_3 P_3 + \mu_5 P_5 + \mu_6 P_6 + \mu_7 P_7 + \mu_{10} P_{10} \quad (9.21)$$

$$[\frac{d}{dt} + \sum_{i=1}^{7} \lambda_i]P_0 = \mu_3 P_3 + \mu_5 P_5 + \mu_6 P_6 + \mu_7 P_7 + \mu_{10} P_{10} \quad (9.22)$$

$$[\frac{d}{dt} + \alpha_m]P_i(t) = \beta_m P_j(t),$$
$$m = 1,2,2,3......,\ j = 0,1.2,3....,\ i = 1\ to\ 7 \quad (9.23)$$

With initial condition (9.24)

$$P_i(t) = 1 \text{ when i = 0 and } P_i = 0 \text{ when i > 0}$$

In this steady state, the derivative of the state probabilities in equation 1 to 5 are set to zero and solving the resulting equations recursively and obtained the following steady-state probabilities:

$$P_3=X_3P_0 \quad P_5=X_5P_0 \quad P_6=X_6P_0 \quad P_7=X_7P_0 \quad P_{10}=X_{10}P_0$$

Probability of full working state (WS) P_0 is determined by using normalizing condition below

$$P_o+ P_3+ P_5+ P_6+ P_7+ P_{10}=1 \tag{9.25}$$

Substituting the values of P_1 to P_7 in terms of P_0 into the normalizing condition in equation (9.24)

$$P_0(1+X_{3+} X_{5+} X_{6+} X_7+X_{10})=1 \tag{9.26}$$

$$P_0 \times d_0 = 1$$

$$P_0 = \frac{1}{d_0} \tag{9.27}$$

where, $X_3 = \frac{\lambda_3}{\mu_3}, X_5 = \frac{\lambda_5}{\mu_5}, X_6 = \frac{\lambda_6}{\mu_6}, X_7 = \frac{\lambda_7}{\mu_7}, X_{10} = \frac{\lambda_{10}}{\mu_{10}}$

$$d_0 = 1 + X_3 + X_5 + X_6 + X_7 + X_{10}$$

Similarly other shovel (KS2 from surface coal Mine, KS12 from surface iron ore mine and KS19 form surface limestone mine) and dumper (BD3, BD4, BD5, BD6, KD7. KD8, KD9, KD10 from surface coal mine, BD13, BD14, BD15, KD16, KD17, KD18 from surface iron ore mine and BD21, BD22, BD23, KD24, KD25, KD25) will follows the same procedure to generate the mathematical models and to determine the reliability of each shovel and dumper. The reliability of the each shovel and dumper from all three mines were calculated using these mathematical model and same as calculated using the RWB also. The obtained reliability values in Morkov model and RBD with error as tabulated in Table 9.2

9.2 Validation of Obtained Results

To validate the results obtained from all surface mines, the percentage error between the field data (Weibull distribution) and predicted data (RBD and Markov model) were calculated. The details are given in Table 9.2 (for all surface mines) and shown in Figure 5.5, 5.6 and 5.7 (for surface coal mine, surface iron ore mine and surface limestone mine respectively). When comparing Weibull 2 parameter distribution with RBD and Markov model, it is found that the maximum error is 16.89% and 16.81% respectively for KS1 in surface coal mine. Similarly the minimum error is 1.782% and 1.818% (i.e., RBD and Markov model) respectively for KD8. When comparing Weibull 3 parameter distribution with RBD and Markov model, it is found that the maximum error is 17.927% and 16.727% respectively for KS12 in surface iron ore mine. Similarly the minimum error is 2.869% and 2.786% (i.e., RBD and Markov model) respectively for BD13. Similarly, when comparing Weibull distribution with RBD and Markov model, it is found that the maximum error is 15.569% and 15.16% respectively for Weibull 2 parameter distribution for KS19 in surface limestone mine. Similarly the minimum error is 3.222% and 3.343% (i.e., RBD and Markov model) respectively for Weibull 3 parameter distribution for BD23. Hence, it is concluded that the predicted models are satisfactory and can be used for prediction of the reliability of shovels and dumpers with reasonably accuracy in surface mines.

Table 9.2 Reliability Comparative statement of shovel and dumper: Weibull distribution, RBD and Markov Model

Systems		**R(t) Weibull distribution**	**R(t) RBD**	**R(t) MM**	**% in Error (Weibull & RBD**	**% in Error (Weibull & MM)**
Surface coal mine	KS1	0.373	0.3103	0.31	16.810	16.890
	KS2	0.285	0.3182	0.318	11.649	11.579
	BD3	0.356	0.3044	0.304	14.494	14.607
	BD4	0.269	0.2478	0.248	7.881	7.807
	BD5	0.347	0.29	0.29	16.427	16.427
	BD6	0.334	0.3466	0.341	3.772	2.096
	KD7	0.332	0.3076	0.308	7.349	7.229
	KD8	0.275	0.2701	0.27	1.782	1.818
	KD9	0.268	0.3093	0.309	15.410	15.299
	KD10	0.291	0.3265	0.327	12.199	12.371
Surface iron ore mine	KS11	0.312	0.2652	0.259	15.000	16.987
	KS12	0.275	0.2257	0.229	17.927	16.727
	BD13	0.359	0.3487	0.349	2.869	2.786
	BD14	0.342	0.3241	0.319	5.234	6.725
	BD15	0.332	0.3192	0.319	3.855	3.916
	KD16	0.409	0.3635	0.359	11.125	12.225
	KD17	0.393	0.4156	0.401	5.751	2.036
	KD18	0.394	0.3682	0.327	6.548	17.005

Surface limestone mine	KS19	0.343	0.2896	0.291	15.569	15.160
	KS20	0.348	0.3135	0.314	9.914	9.770
	BD21	0.325	0.2858	0.277	12.062	14.769
	BD22	0.292	0.3381	0.328	15.788	12.329
	BD23	0.329	0.3396	0.34	3.222	3.343
	KD24	0.362	0.3012	0.301	16.796	16.851
	KD25	0.334	0.2863	0.279	14.281	16.467
	KD26	0.304	0.2594	0.259	14.671	14.803

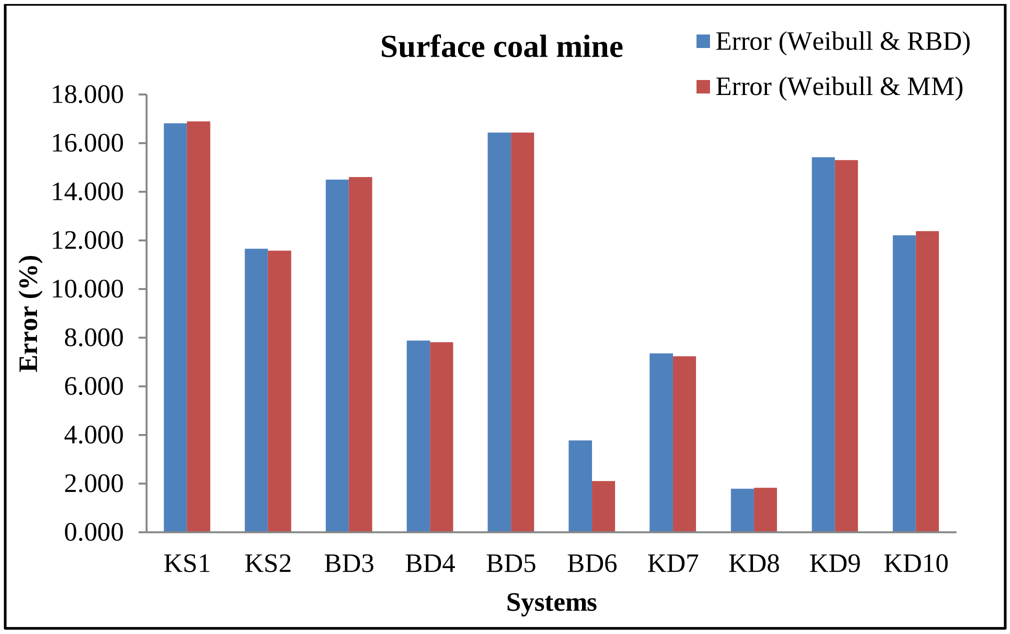


Figure 9.4 Error plot between the Weibull distribution, RBD and Markov model for surface coal mine

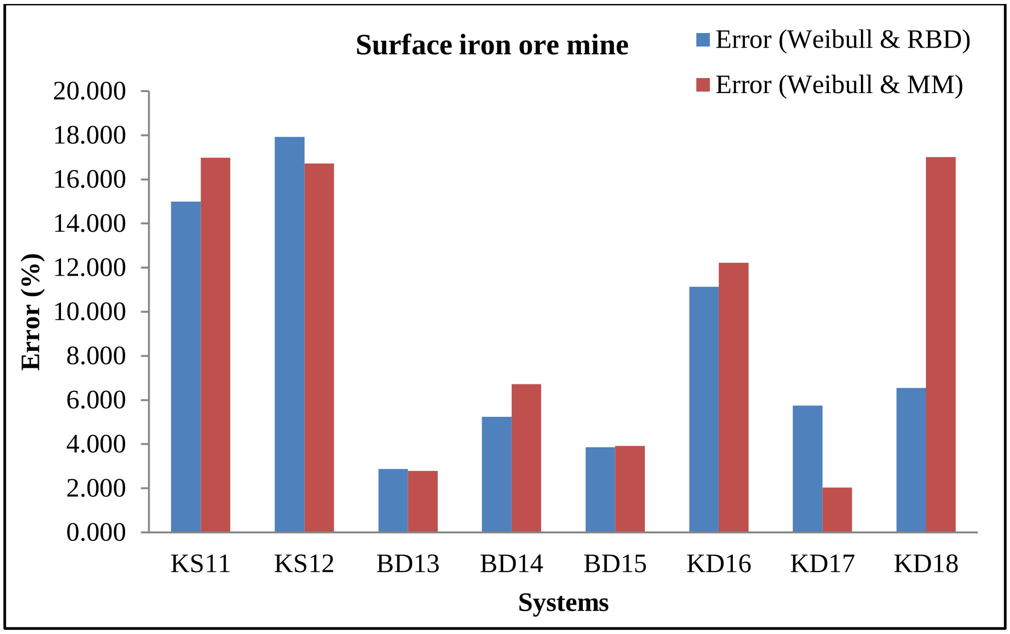


Figure 9.5 Error plot between the Weibull distribution, RBD and Markov model for surface iron ore mine

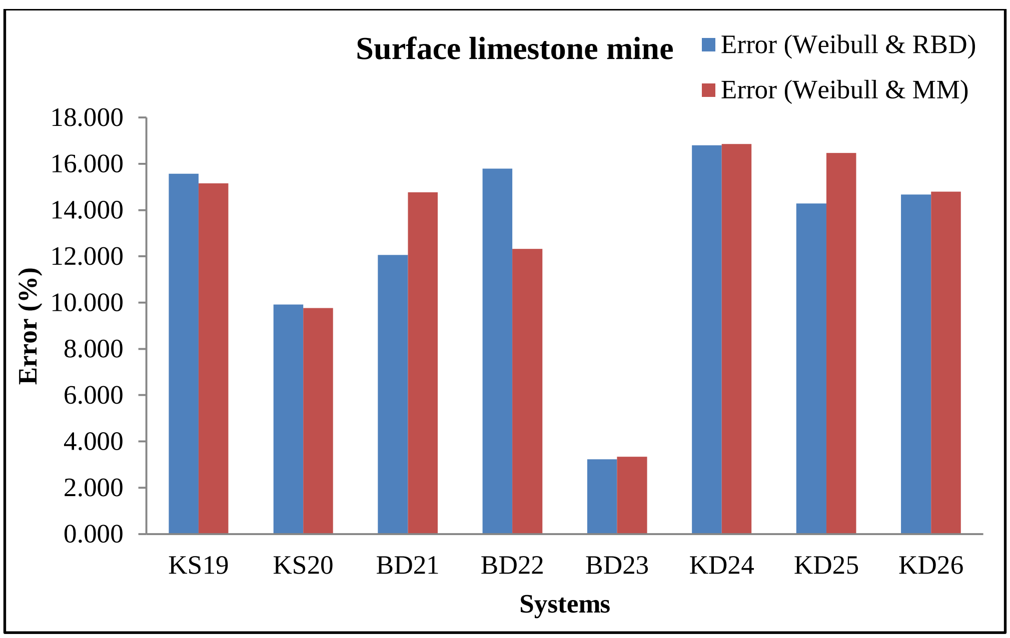


Figure 9.6 Error plot between the Weibull distribution, RBD and Markov model for surface limestone mine

CHAPTER 10

CONCLUSION, RECOMMENDATIONS AND SCOPE FOR FUTURE WORK

10.1 Conclusions

In the present research work, the reliability, availability and maintainability of the shovel-dumper system in surfaces mines (i.e., surface coal mine, surface iron ore mine and surface limestone mine) is analyzed using Reliability Isograph Workbench. Based on the failure data from three surface mines, RBD and Markov model are developed using Reliability Work Bench to assess the reliability of shovels and dumpers. Also, the mathematical models are developed using the same failure data to predict reliability of shovel and dumper. Mathematical equations were generated for developed RBD and Markov models. These mathematical equations are compared with RBD and Markov model. The following conclusions were drawn:

Common conclusions for three mines:

1. The trend and correlation test is performed based on collected TBF and TTR of all shovels and dumpers from the surface coal mine, surface iron ore mine and surface limestone mine. The trend and correlation plots are drawn between the cumulative TBF, TTR and number of failures. It is observed that the relationship between number of failures and TBD/TTR is linear and there is trend in the data (Refer to Figures 6.1 (a) to 6.26 (a)). The scatter plots also drawn between two variables i.e., (i^{th} TBF and $(i-1)^{th}$ TBF) and it is observed that the data is widely scattered and therefore, there is no correlation between consecutive failure data (refer to Figure 6.1 (b) to 6.26 (b)).
2. The calculated values of U - statistic for TBF and TTR are more than the values obtained from the null hypothesis (refer to Table 6.13). It concluded that, the TBF and TTR have null hypothesis is rejected with a confidence interval of 95% all shovels and dumpers.
3. By observing the probability density functions, best fit distribution is identified for TBF and TTR of shovel and dumper. The TBF and TTR of KS1, KS2, KD7, KD8, BD14, BD15, KS20, BD22, BD23, KD24, KD25, KD26 follow the Weibull 2-

parameter distribution and BD3, BD4, BD5, BD6, KD9, KD10, KS11, KS12, BD13, KD16, KD17, KD18, KS19 and BD21 follow the Weibull 3-Parameter distribution (refer to Table 6.14).

4. The Weibull shape parameter (β) of shovel and dumper is determined using the best fit distribution. It is observed that the β of KS1, KS2, BD4, BD5, KD7, KD8, KD9, KD10, KS11, KS12, BD14, BD15, KS19, KS20, BD21, BD22, BD23, KD25 and KD26 is less than 1 (refer to Table 6.14) and it is concluded that shovels and dumpers have defects in manufacturing or early design. i.e., higher probability for early failures upon first use. The β of BD3, KD6, BD13 and KD24 is equal to one and it concluded that dumpers are in arbitrary causes of failure and also indicates that early life has characterized by a higher rate of normal failures or failures which take less time for repair. Similarly, the β of KD16, KD17 and KD18 is greater than 1 (refer to Table 6.14) and it is concluded that dumpers having probability for failure increases due to expiration of design lifetime.

Conclusions for surface coal mine:

1. By observing the collected TBF and TTR in surface coal mine, it is found that the SS5 (electrical subsystem) and SS7 (hydraulic subsystem) are failed more number of times in shovel KS1 i.e., 29.8% and SS7 (hydraulic subsystem) is failed more number of times in KS2 i.e., 28.7%. Similarly, DS4 (electrical subsystem) is failed more number of times in dumpers of BD3, BD4, KD7, KD8, KD9 and KD10 i.e., 23.2%, 23.9%, 40.9%, 29.1, 36.1% and 35.8% respectively. DS5 (Engine subsystem) and DS10 (transmission subsystem) are failed more number of times in BD6 and BD5 i.e., 42.2% and 36.6% respectively (refer to Table 5.4).
2. It is found that the maximum availability is 0.9033 for KS1, because KS1 has less MTBF (43.934) and MTTR (4.693 hrs). It is also found that the maximum maintainability of KS1, KS2, BD6 and KD8 is 0.99 and their MTTR is 4.693 hrs, 7.487 hrs, 18.552 hrs and 7.331 hrs respectively (refer to Table 7.1).
3. It is found that reliability of KS1 and KS2 is 0.373 and 0.285 respectively. Similarly, reliability of BD3, BD4, BD5, BD6, KD7, KD8, KD9 and KD10 is 0.356, 0.269, 0.347, 0.334, 0.332, 0.275, 0.268 and 0.291 respectively (refer to Table 7.2). It is

concluded that reliability of KS2 is less than KS1, because KS2 have more repair hours (MTTR=7.487 hrs) than KS1 (MTTR=4.693 hrs) (refer to Table 5.5). Reliability of BD4 is less than BD3, BD5 and BD6, because it has more number of failures and less MTBF (refer to Table 5.5) and reliability of KD8 and KD9 are less when compared to KD7 and KD10 because of more number of failures and less MTBF (refer to Table 5.5).

4. RBD models and mathematical equations are developed for all shovels and dumpers based on failure rate of subsystems (refer to Table 5.3 and Figure D.1 to D.8) and given in Annexure-D. However, RBD models (refer to Figure 8.1 and 8.2) and mathematical equations for KS1 and BD3 (refer equation 8.1 and 8.2) are given in chapter 8.
5. Based on the Weibull distribution, series-parallel configuration of RBD is developed for G1 (i.e., dumpers BD3, BD4, KD7 and KD8 are working together in series and parallel with shovel KS1) and G2 (dumpers BD5, BD6, KD9 and KD10 are working together in series and parallel with shovel KS2) using Isograph Reliability Workbench to improve the reliability (refer to Figure 8.17 and 8.18). It is observed that the reliability of series-parallel configuration of shovel and dumper is improved i.e., 0.7034 in G1 and 0.737 in G2 (refer to Table 8.3) when compared to series configuration. Also, mathematical models are developed for G1 and G2 (refer equations 8.28 and 8.29).
6. The Markov models and mathematical equations are developed for the overall systems of all shovels and dumpers based on both failure rate and repair rate with respect to their RBD and given in Annexure-D (refer to Table 5.3 and Figure D.42 to D.50). However, Markov model (refer to Figure 9.1) and mathematical equation for KS1 (refer to equation 9.9) are given in chapter 9. The state S_0 is considered as working condition and other states such as S_2 (SS2), S_3 (SS3), S_5 (SS5), S_6 (SS6), S_7 (SS7), S_9 (SS9) and S_{10} (SS10) are failed state due to failure of one or more subsystems in shovel KS1 (refer to Figure 9.1). The probability of the success rate of all shovels and dumpers are similar to the Weibull distribution (refer to Table 9.2). Also, the mathematical model was developed based on the failure state and working states of subsystems of shovel KS1 (refer to equation 9.9).

Conclusions for surface iron ore mine:

1. By observing the collected TBF and TTR in surface iron ore mine, it is found that SS3 (Bucket) and SS6 (hydraulic suspension subsystem) are failed more number of times in KS11 i.e., 29% and SS6 (hydraulic suspension subsystem) is failed more number of times in KS12 i.e., 48.3%. Similarly, DS8 (structural subsystem) is failed more number of times in BD13, BD14, BD15, KD16, KD17 and KD18 i.e., 34.1%, 31.2%, 34.2%, 20%, 40.5% and 29.3% respectively. DS5 (Engine subsystem) and DS6 (hydraulic suspension subsystem) are failed more number of times in KD16 i.e., 20% (refer to Table 5.8).
2. It is found that the maximum availability is 0.9447 for KS11 because shape parameter of KS1is (β=0.5936) is less than other shovel and dumpers (refer to Table 6.14 for β). The KS11, KS12, BD15 and KD18 having maximum maintainability of 1 and it observed that MTTR of KS11, KS12, BD15 and KD18 is less i.e., 11.0732 hrs, 3.6741 hrs, 15.7554 hrs and 36.5895 hrs respectively (refer to Table 7.1).
3. It is found that reliability of KS11 and KS12 are 0.312 and 0.275 respectively. Similarly reliability of BD13, BD14, BD15, KD16, KD17 and KD18 are 0.359, 0.342, 0.332, 0.409, 0.393 and 0.394 respectively (refer to Table 7.2). It is concluded that reliability of KS12 is less than KS11 because more number of failure and more MTBF in KS12 (MTBF=189.0026 hrs) than KS11 (MTBF=59.3813 hrs) (refer Table 5.9). Reliability of BD13, BD14 and BD15 are almost equal, but less reliability than KD16, KD17 and KD18 because more number of failures and less MTBF in BD13, BD14 than BD15 i.e., 109.746 hrs, 90.3619 hrs and 110.0758 hrs respectively (refer Table 5.9).
4. RBD models and mathematical equations are developed for all shovels and dumpers based on failure rate of subsystems (refer to Table 5.3 and Figure D.9 to D.14) and given in Annexure-D. However, RBD models (refer to Figure 8.3 and 8.4) and mathematical equations for KS11 and BD13 (refer equation 8.3 and 8.4) are given in chapter 8.

5. Based on the Weibull distribution the series-parallel configuration of RBD is developed for G1 (i.e., dumpers BD13, BD14 and BD15 are working together in series and parallel with shovel KS11) and G2 (dumpers KD16, KD17 and KD18 are working together in series and parallel with shovel KS12) using Isograph Reliability Workbench to improve the reliability. It is observed that the reliability of series-parallel configuration of shovel and dumper is improved i.e., 0.5853 in G1 and 0.6 in G2. Also, mathematical models are developed for G1 and G2 (refer equations 8.30 and 8.31).
6. The Markov models and mathematical equations are developed for the overall systems of all shovels and dumpers based on both failure rate and repair rate with respect to their RBD and given in Annexure-D (refer to Table 5.3 and Figure D.51 to D.57). However, Markov model (refer to Figure 9.2) and mathematical equation for KS11 (refer to equation 9.18) are given in chapter 9. The state S_0 is considered as working condition and other states such as S_2 (SS2), S_3 (SS3), S_5 (SS5), S_6 (SS6), S_7 (SS7), S_9 (SS9) and S_{10} (SS10) are failed state due to failure of one or more subsystems in shovel KS11 (refer to Figure 9.2). The probability of the success rate of all shovels and dumpers are similar to the Weibull distribution (refer to Table 9.2). Also, the mathematical model was developed based on the failure state and working states of subsystems of shovel KS11 (refer to equation 9.18).

Conclusion for surface limestone mine:

1. By observing the collected TBF and TTR in surface limestone mine, it is found that SS7 (hydraulic subsystem) is failed more number of times in KS19 and KS20 i.e., 28.79% and 24.29% respectively. Also, DS10 (transmission subsystem) is failed more number of times in BD21 and BD22 i.e., 25.27% and 28.87 respectively. Similarly, DS4 (electrical subsystem) is failed more number of times in BD23, KD24, KD25 and KD26 i.e., 26.32, 27.59, 40.54 and 48.28 respectively (refer to Table 5.12).
2. It is found that the maximum availability is 0.9595 for KS19 because KS19 have less repair rate (MTTR=6.841) and it follows Weibull 3-parameters distribution (i.e., η=85.12, β=0.84, γ=−1.299) (refer to Table 6.14). The KS19, KS20, KD24, KD25 and KD26 having maximum maintainability of 1 and it observed that MTTR of KS19,

KS20, KD24, KD25 and KD26 is less i.e., 6.841 hrs, 9.401 hrs, 7.486 hrs and 10.031 hrs respectively (refer to Table 7.1).

3. It is found that reliability of KS19 and KS20 are 0.343 and 0.348 respectively. Similarly reliability of BD21, BD22, BD23, KD24, KD25 and KD26 are 0.325, 0.292, 0.329, 0.362, 0.334 and 0.304 (refer to Table 7.2). It is concluded that reliability of KS19 and KS20 almost equal and good reliability compared to the other two surface mine i.e., coal mine and iron ore mine. Reliability of the BD22 is less than others i.e., BD21, BD23 KD24, KD25, and KD26 because number of failures and less MTBF i.e., MTBF of BD22 is 52.226 hrs (refer to Table 5.13).
4. RBD models and mathematical equations are developed for all shovels and dumpers based on failure rate of subsystems (refer to Table 5.3 and Figure D.15 to D.20) and given in Annexure-D. However, RBD models (refer to Figure 8.5 and 8.6) and mathematical equations for KS19 and BD21 (refer equation 8.5 and 8.6) are given in chapter 8.
5. Based on the Weibull distribution the series-parallel configuration of RBD is developed for G1 (i.e., dumpers BD21, BD22 and BD23 are working together in series and parallel with shovel KS19) and G2 (i.e., dumpers KD24, KD25 and KD26 are working together in series and parallel with shovel KS20) using Isograph Reliability Workbench to improve the reliability. It is observed that the reliability of series-parallel configuration of shovel and dumper is improved i.e., 0.497 in G1 and 0.521 in G2. Also, mathematical models are developed for G1 and G2 (refer equations 8.32 and 8.33).
6. The Markov models and mathematical equations are developed for the overall systems of all shovels and dumpers based on both failure rate and repair rate with respect to their RBD and given in Annexure-D (refer to Table 5.3 and Figure D.58 to D.64). However, Markov model (refer to Figure 9.3) and mathematical equation for KS19 (refer to equation 9.27) are given in chapter 9. The state S_0 is good working condition and other stats such as S_1 (SS1), S_2 (SS2), S_3 (SS3), S_4 (SS4), S_5 (SS5), S_6 (SS6), S_7 (SS7), and S_9 (SS9) are failed state due to failure of one or more subsystems in shovel KS19 (refer to Figure 9.3). The probability of the success rate of all shovels and dumpers are similar to the Weibull distribution (refer to Table 9.2). Also, the

mathematical model was developed based on the failure state and working states of subsystems of shovel KS19 (refer to equation 9.27).

Comparative study for all three mines: For shovel, the highest failure rate was found in hydraulic sub-system for coal as well as limestone mines (29.8% and 28.7%, respectively, for KS1 and KS2 for coal mine and 28.79% and 24.29% for KS19 and KS20, respectively for limestone mine). On the contrary, engine failure (29% and 48.3% for KS11 and KS12, respectively) had the highest failure rate in iron ore mines. Similarly, for dumper system, electrical sub-system failure was the highest for coal and limestone mines (23.2%, 23.9%, 40.9%, 29.1%, 36.1% and 35.8% for BD3, BD4, KD7, KD8, KD9 and KD10, respectively for coal mine and 26.32%, 27.59%, 40.54% and 48.28% for BD23, KD24, KD25 and KD26, respectively for limestone mine). However, the structural system failure was the highest in iron ore mines (34.1%, 31.2%, 34.2%, 20%, 40.5% & 29.3% for BD13, BD14, BD15, KD16, KD17 and KD18, respectively). Among the other sub-systems, electrical system (KS1 - 29.8%), transmission system (BD5 - 36.6%) and engine failure (BD6 - 42.2%) in coal mine; bucket system (KS11 - 29%), engine (KD16 - 20%) and hydraulic suspension system failure (KD16 - 20%) in iron ore mine and transmission system failure (BD21 - 25.27%; BD22 - 28.87%) in limestone mine were observed.

Reliability improvement was studied using Weibull distribution modelling strategies. The goodness of fit revealed 3-parameter Weibull distribution as appropriate for coal and iron ore mine (0.028 - KS1, 0.0263 - KS2, 0.0335 - BD3, 0.0308 - BD4, 0.0302 - BD5, 0.035 - KD6, 0.0161 - KD7, 0.0208 - KD8, 0.0253 - KD9 and 0.034 - KD10 for coal mine; 0.0411 - KS11, 0.0396 - KS12, 0.0215 - BD13, 0.0263 - BD14, 0.303 - BD15, 0.0614 - KD16, 0.0402 - KD17 and KD18 - 0.0285 for iron ore mine), but a 2-parameter Weibull distribution as a delineation of the observed distribution for limestone mine (0.0352 - KS19, 0.154 - KS20, 0.0376 - BD21, 0.0239 - BD22, 0.0254 - BD23, 0.0191 - KD24, 0.0264 - KD25 and 0.0247 - KD26).

KS1 (0.9033 availability and 0.9999 maintainability) and BD6 (0.8829 availability and 0.9995 maintainability) had the highest availability and maintainability values for shovel and dumper in coal mine. On the other hand, KS11 (0.9447 availability and 1.0 maintainability) and KD18 (0.8789 availability and 0.9993 maintainability) obtained the highest values for iron ore mine. In case of limestone mine, KS19 (0.9595 availability and 1 maintainability) and KD24 (0.9179 availability and 1.0 maintainability) was better than all others.

Furthermore, KS1 and BD3 in coal mine, KS11 and KD16 in iron ore mine and KS19 and KD24 in limestone mine were the most reliable equipment during the operating hours of the mines. In addition, 90% reliability was achieved at 12.87 and 12.9 hours for KS1 and KD10, respectively in coal mine and 12.82 and 18.47 hours for KS12 and BD14 in iron ore mine. In limestone mine, 12.6 and 5.36 hours (KS20 and BD22, respectively) were the least time taken to attain 90% reliability.

A reliability of 80% was achieved at 2.58 hours by KS12 in iron ore mine for shovel and dumper BD22 achieved at 10.44 hours in limestone mine. The rest of the dumpers and shovel required much longer time to reach expected reliability. Contrarily, shovel KS1 of coal mine took 17.03 hours and dumper BD22 of limestone mine took 10.45 hours to achieve 70% reliability. Thus, Komatsu shovel and dumper equipment performed much better than BEML equipment based on its utilisation in the three mines.

RBD and Markov model was used to develop mathematical model for shovel and dumper systems. KS1 (0.6897 RBD) and BD6 (0.8134 RBD) had the highest reliability in coal mine. KS12 (0.7749 MM) and BD14 (0.8134 RBD) were the most reliable in iron ore mine. On the other hand, in limestone mine, KS19 (0.7304 RBD) and BD21 (0.7442 RBD) were the reliable equipment. The results showed that RBD modelling was more effective than Morkov modelling for all the three mines.

The percentage error between the field data (Weibull distribution) and predicted data (RBD and Markov model) to validate results obtained for all surface mines. (refer to Table 9.2). When comparing Weibull 2 parameter distribution with RBD and Markov model, it is found that the maximum error is 16.89% and 16.81% respectively for KS1 in surface coal mine. Similarly the minimum error is 1.782% and 1.818% (i.e., RBD and Markov model) respectively for KD8. When comparing Weibull 3 parameter distribution with RBD and Markov model, it is found that the maximum error is 17.927% and 16.727% respectively for KS12 in surface iron ore mine. Similarly the minimum error is 2.869% and 2.786% (i.e., RBD and Markov model) respectively for BD13. Similarly, when comparing Weibull distribution with RBD and Markov model, it is found that the maximum error is 15.569% and 15.16%

respectively for Weibull 2 parameter distribution for KS19 in surface limestone mine. Similarly the minimum error is 3.222% and 3.343% (i.e., RBD and Markov model) respectively for Weibull 3 parameter distribution for BD23. Hence, it is concluded that the predicted models are satisfactory and can be used for prediction of the reliability of shovels and dumpers with reasonably accuracy in surface mines.

10.2 Recommendations

The following are the recommendations to improve the reliability/performance of shovel-dumper system in Indian surface mines based on results of present study:

1. Proper maintenance and preventive maintenance record and training of maintenance crew will help in improving the reliability. Detailed descriptions of causes of failure and their analysis, statistics on the number of crew required per failure and pre-failure delay conditions have to be record.
2. By adopting real-time maintenance procedure will help in improving the reliability of equipment.
3. To optimize maintenance, proper stock plans, registers, proper replacement policy and inspection based on failure mode and rate of various components of any equipment will help to reduce MTTR.
4. With the help of Weibull parameters based on the failure data, the condition of any system/equipment can be assessed.
5. By adopting the series-parallel configuration for shovel-dumper system based on probability distributions the reliability can be improved.
6. Results of reliability analyses should be utilized to prepare a maintenance plan considering the most failiure susystems/components. Preparing an appropriate maintenance plan considering the subsytems of each system (shovel and dumper) reliabilities will increase the machines availability, thus decreasing the direct and indirect costs caused by unplanned down times of the shovel-dumper system in any surface mines.

10.3 Scope of Future Work

1. The present research work can be extended, where time dependent failure and repair rates would be considered. Then, the performance of equipment can be improved.

2. Genetic algorithms can be used for equipment in surface mines to improve reliability further.
3. Studies using fault tree analysis, failure mode and effects analysis (FMEA) and artificial neural network (ANN) have to be carried out for improve the overall reliability of equipment in surface mines.

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ANNEXURE-A

Table A.1 Failure and repair data of various subsystems of shovel and dumper in surface coal mine

Systems	No. of failures	Start Date	Start Time	End date	End Time	TBF, hrs	Reasons	TTR, hrs	Failure Codes
KS1	1	01-04-2017	13:00:00	01-04-2017	13:12:00	0	Electrical breakdown	0.2	SS5
KS1	2	02-04-2017	06:30:00	02-04-2017	12:01:48	17.3	Electrical breakdown	5.53	SS5
KS1	3	02-04-2017	20:30:00	02-04-2017	23:15:00	8.47	Electrical breakdown	2.75	SS5
KS1	4	03-04-2017	06:00:26	03-04-2017	14:00:00	6.76	Engine rpm become slow	7.99	SS6
KS1	5	04-04-2017	02:30:22	04-04-2017	11:45:10	12.51	Engine rpm become slow	9.25	SS6
KS1	6	04-04-2017	21:00:00	04-04-2017	23:45:55	9.25	Electrical breakdown	2.77	SS5
KS1	7	05-04-2017	07:00:17	05-04-2017	12:45:39	7.24	Engine not starting	5.76	SS6
KS1	8	07-04-2017	15:30:00	07-04-2017	22:50:00	50.74	Electrical breakdown	7.33	SS5
KS1	9	08-04-2017	07:00:27	08-04-2017	11:45:52	8.17	Engine not starting	4.76	SS6
KS1	10	08-04-2017	19:10:00	08-04-2017	20:30:00	7.4	Electrical breakdown	1.33	SS5
KS1	11	09-04-2017	10:45:00	09-04-2017	11:40:00	14.25	Electrical breakdown	0.92	SS5
KS1	12	10-04-2017	07:30:00	10-04-2017	10:15:00	19.83	Track pin missing/came out	2.75	SS10
KS1	13	12-04-2017	17:55:00	12-04-2017	18:20:00	55.67	Hydraulic oil temperature raising	0.42	SS7
KS1	14	12-04-2017	21:00:00	12-04-2017	22:50:00	2.67	Engine Initial problem (engine not starting)	1.83	SS6
KS1	15	15-04-2017	02:15:05	15-04-2017	02:20:35	51.42	Hydraulic oil leakage	0.09	SS7
KS1	16	15-04-2017	09:00:00	15-04-2017	12:15:00	6.66	Bucket hinge pin came out	3.25	SS3
KS1	17	16-04-2017	08:10:00	16-04-2017	08:20:00	19.92	Electrical breakdown	0.17	SS5
KS1	18	16-04-2017	08:45:00	16-04-2017	12:45:00	0.42	Electrical breakdown	4	SS5
KS1	19	17-04-2017	04:45:00	17-04-2017	10:20:00	16	Dump cylinder top pin came out	5.58	SS2
KS1	20	18-04-2017	13:45:00	18-04-2017	14:50:00	27.42	Electrical breakdown	1.08	SS5
KS1	21	19-04-2017	04:00:00	19-04-2017	04:20:00	13.17	Electrical breakdown	0.33	SS5
KS1	22	19-04-2017	06:10:00	19-04-2017	08:50:00	1.83	Electrical breakdown	2.67	SS5
KS1	23	19-04-2017	10:00:00	19-04-2017	12:30:00	1.17	Engine not starting	2.5	SS6
KS1	24	23-04-2017	17:40:00	22-05-2017	18:00:00	101.17	A/C not working	0.33	SS5
KS1	25	23-05-2017	07:30:00	23-05-2017	08:00:00	13.5	Initial problem (engine not starting)	0.5	SS6
KS1	26	27-05-2017	19:00:00	27-05-2017	21:45:00	107	Electrical breakdown	2.75	SS6
KS1	27	11-06-2017	15:01:00	12-06-2017	03:00:00	353.27	Cabin door locked	11.98	SS9

KS1	28	12-06-2017	16:30:00	12-06-2017	17:00:00	13.5	Wireless set not working	0.5	SS9
KS1	29	13-06-2017	10:00:00	13-06-2017	20:40:00	17	Bucket hinge pin came out	10.67	SS3
KS1	30	14-06-2017	07:30:00	14-06-2017	08:15:00	10.83	Cabin door lock locked	0.75	SS9
KS1	31	14-06-2017	13:00:00	14-06-2017	13:30:00	4.75	Cabin door lock locked	0.5	SS9
KS1	32	17-06-2017	21:45:00	17-06-2017	21:50:00	80.25	Hydraulic oil leakage from lift cylinder	0.08	SS7
KS1	33	24-06-2017	08:31:00	24-06-2017	18:00:00	154.68	Bucket replacement	9.48	SS3
KS1	34	24-06-2017	18:00:01	25-06-2017	10:20:00	0	Bucket replacement	16.33	SS3
KS1	35	25-06-2017	23:01:00	26-06-2017	02:30:00	12.68	Problem occurred in cabin door	3.48	SS9
KS1	36	26-06-2017	17:45:00	27-06-2017	00:40:35	15.25	Hydraulic oil leakage	6.93	SS7
KS1	37	28-06-2017	17:00:00	28-06-2017	18:45:00	40.32	Hydraulic oil leakage	1.75	SS7
KS1	38	30-06-2017	15:50:00	30-06-2017	16:30:00	45.08	Tooth point missed	0.67	SS3
KS1	39	30-06-2017	18:20:00	30-06-2017	18:45:00	1.83	Tooth point missed	0.42	SS3
KS1	40	01-07-2017	06:25:00	01-07-2017	10:30:00	11.67	Hydraulic oil leakage	4.08	SS7
KS1	41	01-07-2017	13:00:00	01-07-2017	19:20:00	2.5	Initial problem (engine not starting)	6.33	SS5
KS1	42	01-07-2017	20:30:00	02-07-2017	17:30:00	1.17	Initial problem (engine not starting)	21	SS5
KS1	43	02-07-2017	20:30:00	03-07-2017	13:45:00	3	Initial problem (engine not starting)	17.25	SS5
KS1	44	03-07-2017	17:15:00	03-07-2017	20:30:00	3.5	Hoist cylinder hose failure	3.25	SS7
KS1	45	04-07-2017	15:50:00	04-07-2017	18:00:00	19.33	Electrical breakdown	2.17	SS5
KS1	46	05-07-2017	21:45:00	05-07-2017	22:00:00	27.75	Accumulator problem	0.25	SS6
KS1	47	08-07-2017	11:00:00	08-07-2017	12:30:00	61	A/C not working	1.5	SS5
KS1	48	08-07-2017	15:01:00	08-07-2017	20:40:00	2.52	A/C not working	5.65	SS5
KS1	49	09-07-2017	11:30:00	09-07-2017	13:40:00	14.83	Electrical breakdown	2.17	SS5
KS1	50	10-07-2017	08:31:00	10-07-2017	12:30:00	18.85	A/C not working	3.98	SS5
KS1	51	11-07-2017	08:31:00	11-07-2017	13:10:00	20.02	A/C not working	4.65	SS5
KS1	52	12-07-2017	10:00:00	13-07-2017	01:40:00	20.83	Hydraulic hose failed	15.67	SS7
KS1	53	12-07-2017	16:00:00	12-07-2017	17:00:00	9.67	Tooth point lock missing	1	SS3
KS1	54	13-07-2017	15:30:00	13-07-2017	16:30:00	22.5	Tooth point missed	1	SS3
KS1	55	15-07-2017	08:16:00	15-07-2017	12:00:00	39.77	Hydraulic oil leakage	3.73	SS7
KS1	56	15-07-2017	12:20:00	15-07-2017	13:30:00	0.33	Hydraulic hose failed	1.17	SS7
KS1	57	17-07-2017	23:30:00	18-07-2017	00:30:00	58	Wiper fixing	1	SS9
KS1	58	20-07-2017	21:30:00	21-07-2017	00:40:00	69	Foot step ladder damaged	3.17	SS9
KS1	59	21-07-2017	01:00:00	21-07-2017	01:15:00	0.33	Problem occurred in Problem occurred in operator	0.25	SS9

KS1	60	23-07-2017	03:55:00	23-07-2017	04:20:00	50.67	Initial problem (engine not starting)	0.42	SS6
KS1	61	25-07-2017	22:00:00	26-07-2017	00:30:22	65.67	Hydraulic hose failed	2.51	SS7
KS1	62	28-07-2017	13:30:00	28-07-2017	14:55:00	60.99	Hydraulic oil temperature raising	1.42	SS7
KS1	63	31-07-2017	09:01:00	31-07-2017	10:15:00	66.1	Hydraulic oil temperature raising	1.23	SS7
KS1	64	02-08-2017	03:30:00	02-08-2017	11:40:00	41.25	Hydraulic oil leakage	8.17	SS7
KS1	65	04-08-2017	15:30:36	04-08-2017	17:30:14	51.84	Initial problem (engine not starting)	1.99	SS5
KS1	66	08-08-2017	01:30:00	08-08-2017	01:35:00	80	Hydraulic oil temperature raising	0.08	SS7
KS1	67	13-08-2017	19:00:00	14-08-2017	10:50:00	137.42	Electrical breakdown	15.83	SS5
KS1	68	14-08-2017	22:00:00	14-08-2017	22:10:00	11.17	Hoist operation slow	0.17	SS6
KS1	69	18-08-2017	16:00:00	19-08-2017	01:25:00	89.83	Engine coolant leaking	9.42	SS6
KS1	70	25-08-2017	13:00:00	25-08-2017	13:15:00	155.58	Hydraulic oil temperature raising	0.25	SS7
KS1	71	25-08-2017	23:00:00	26-08-2017	01:30:00	9.75	Hydraulic oil leakage	2.5	SS7
KS1	72	27-08-2017	11:30:00	27-08-2017	12:50:00	34	Alternator not working	1.33	SS5
KS1	73	27-08-2017	14:00:00	27-08-2017	18:00:00	1.17	Engine rpm become slow	4	SS6
KS1	74	29-08-2017	06:10:00	29-08-2017	13:00:00	36.17	Initial problem (engine not starting)	6.83	SS6
KS1	75	31-08-2017	10:30:00	01-09-2017	16:45:00	45.5	Bucket is cracked	30.25	SS3
KS1	76	02-09-2017	10:30:00	02-09-2017	13:30:00	17.75	Hydraulic hose failed	3	SS7
KS1	77	03-09-2017	06:15:00	03-09-2017	11:30:00	16.75	Hydraulic hose failed	5.25	SS7
KS1	78	04-09-2017	17:15:00	04-09-2017	18:35:00	29.75	Tooth point missed	1.33	SS3
KS1	79	04-09-2017	23:30:48	04-09-2017	23:55:46	4.93	Initial problem (engine not starting)	0.42	SS5
KS1	80	05-09-2017	03:30:40	05-09-2017	03:50:17	3.58	Initial problem (engine not starting)	0.33	SS5
KS1	81	06-09-2017	23:30:29	06-09-2017	23:50:56	43.67	Initial problem (engine not starting)	0.34	SS5
KS1	82	07-09-2017	07:30:00	07-09-2017	08:15:00	7.65	Dump cylinder top pin came out	0.75	SS2
KS1	83	09-09-2017	07:00:00	09-09-2017	22:30:00	46.75	Tooth point adapter missing	15.5	SS3
KS1	84	22-09-2017	09:00:39	22-09-2017	12:40:30	298.51	Hydraulic oil leakage	3.66	SS7
KS1	85	22-09-2017	15:01:00	22-09-2017	21:30:00	2.34	Radiator leakage	6.48	SS6
KS1	86	25-09-2017	17:35:00	25-09-2017	18:50:00	68.08	Hoist operation slow	1.25	SS7
KS1	87	01-10-2017	13:15:00	01-10-2017	13:40:00	138.42	Tooth point missed	0.42	SS3
KS1	88	01-10-2017	17:50:26	01-10-2017	18:00:32	4.17	Tooth point missed	0.17	SS3
KS1	89	03-10-2017	23:00:00	04-10-2017	05:20:00	52.99	Hydraulic hose failed	6.33	SS7
KS1	90	04-10-2017	07:01:00	04-10-2017	09:30:00	1.68	Initial problem (engine not starting)	2.48	SS5
KS1	91	06-10-2017	19:40:00	06-10-2017	20:00:00	58.17	A/C not working	0.33	SS5

KS1	92	07-10-2017	15:30:04	07-10-2017	16:20:53	19.5	Initial problem (engine not starting)	0.85	SS5
KS1	93	10-10-2017	07:30:00	10-10-2017	08:30:00	63.15	Initial problem (engine not starting)	1	SS5
KS1	94	10-10-2017	20:30:00	10-10-2017	21:10:00	12	Initial problem (engine not starting)	0.67	SS5
KS1	95	13-10-2017	00:30:00	13-10-2017	00:50:00	51.33	Tooth point missed	0.33	SS3
KS1	96	13-10-2017	07:30:03	13-10-2017	08:15:45	6.67	Initial problem (engine not starting)	0.76	SS5
KS1	97	14-10-2017	03:50:00	14-10-2017	08:45:07	19.57	Electrical breakdown	4.92	SS5
KS1	98	14-10-2017	10:51:28	14-10-2017	12:30:05	2.11	Engine rpm not raising/lowering	1.64	SS6
KS1	99	15-10-2017	16:00:00	15-10-2017	17:00:00	27.5	Hydraulic oil leakage	1	SS7
KS1	100	16-10-2017	10:15:00	16-10-2017	14:20:00	17.25	A/C not working	4.08	SS5
KS1	101	16-10-2017	23:30:05	16-10-2017	23:50:13	9.17	Initial problem (engine not starting)	0.34	SS5
KS1	102	18-10-2017	06:10:14	18-10-2017	08:50:00	30.33	Electrical breakdown	2.66	SS5
KS1	103	18-10-2017	12:30:00	18-10-2017	14:30:00	3.67	Hydraulic oil leakage	2	SS7
KS1	104	20-10-2017	01:00:00	20-10-2017	01:50:00	34.5	A/C not working	0.83	SS5
KS1	105	22-10-2017	08:31:00	22-10-2017	10:45:00	54.68	Tooth point missed	2.23	SS3
KS1	106	23-10-2017	07:30:00	23-10-2017	07:40:00	20.75	Tooth point adapter missing	0.17	SS3
KS1	107	23-10-2017	15:30:35	23-10-2017	16:00:25	7.84	A/C not working	0.5	SS5
KS1	108	24-10-2017	07:01:00	26-10-2017	22:30:52	15.01	Tooth point adapter missing	63.5	SS3
KS1	109	26-10-2017	23:30:00	27-10-2017	00:30:00	0.99	Head lights problem	1	SS5
KS1	110	27-10-2017	08:16:00	27-10-2017	09:30:00	7.77	Initial problem (engine not starting)	1.23	SS5
KS1	111	27-10-2017	10:05:00	27-10-2017	10:30:00	0.58	Problem occurred in grease injector	0.42	SS7
KS1	112	27-10-2017	10:40:00	27-10-2017	13:00:00	0.17	Problem occurred in grease injector	2.33	SS7
KS1	113	27-10-2017	19:40:10	27-10-2017	22:50:31	6.67	Track rollers problem	3.17	SS10
KS1	114	28-10-2017	08:01:00	28-10-2017	21:30:00	9.17	Track rollers problem	13.48	SS10
KS1	115	30-10-2017	17:30:00	30-10-2017	18:30:00	44	Tooth point missed	1	SS3
KS1	116	31-10-2017	18:15:00	31-10-2017	18:50:00	23.75	Grease container empty	0.58	SS7
KS1	117	01-11-2017	02:50:00	03-11-2017	20:30:00	8	Boom crack	65.67	SS2
KS1	118	04-11-2017	18:40:00	05-11-2017	01:50:16	22.17	Hydraulic oil leakage	7.17	SS7
KS1	119	07-11-2017	13:25:00	07-11-2017	13:45:00	59.58	Tooth point missed	0.33	SS3
KS1	120	09-11-2017	11:30:00	09-11-2017	14:30:00	45.75	Tooth adapter C- clamp and wedge missing	3	SS3
KS1	121	10-11-2017	16:00:00	10-11-2017	23:30:02	25.5	Electrical breakdown	7.5	SS5
KS1	122	11-11-2017	08:00:00	11-11-2017	08:30:00	8.5	Tooth point missed	0.5	SS3
KS1	123	11-11-2017	23:30:35	12-11-2017	01:20:42	15.01	Hydraulic oil leakage	1.84	SS7

KS1	124	14-11-2017	07:01:00	14-11-2017	18:19:35	53.67	Bucket changing work	11.31	SS3
KS1	125	15-11-2017	09:45:00	15-11-2017	11:40:00	15.42	Tooth point missed	1.92	SS3
KS1	126	15-11-2017	16:00:00	15-11-2017	20:30:00	4.33	Hydraulic hose failed	4.5	SS7
KS1	127	15-11-2017	23:01:00	16-11-2017	01:45:00	2.52	Hydraulic oil leakage	2.73	SS7
KS1	128	16-11-2017	15:00:18	16-11-2017	19:00:44	13.26	Hydraulic hose failed	4.01	SS7
KS1	129	16-11-2017	19:45:54	16-11-2017	22:00:50	0.75	Hydraulic hose failed	2.25	SS7
KS1	130	16-11-2017	22:35:28	17-11-2017	03:30:00	0.58	Hydraulic hose failed	4.91	SS7
KS1	131	18-11-2017	09:15:00	18-11-2017	09:30:00	29.75	A/C not working	0.25	SS5
KS1	132	18-11-2017	10:50:00	18-11-2017	14:25:00	1.33	A/C not working	3.58	SS5
KS1	133	19-11-2017	01:00:00	19-11-2017	01:30:00	10.58	Electrical breakdown	0.5	SS5
KS1	134	23-11-2017	19:00:00	24-11-2017	01:30:00	113.5	Hydraulic oil leakage	6.5	SS7
KS1	135	24-11-2017	22:30:13	27-11-2017	18:15:00	21	Hydraulic oil leakage	67.75	SS7
KS1	136	28-11-2017	11:30:00	28-11-2017	20:40:00	17.25	Hydraulic oil leakage	9.17	SS7
KS1	137	29-11-2017	04:30:33	29-11-2017	09:40:00	7.84	Hydraulic oil leakage	5.16	SS7
KS1	138	29-11-2017	21:15:00	29-11-2017	22:15:00	11.58	Engine rpm not raising/lowering	1	SS6
KS1	139	30-11-2017	11:30:00	30-11-2017	15:15:00	13.25	Hydraulic hose failed	3.75	SS7
KS1	140	30-11-2017	16:45:00	30-11-2017	17:15:00	1.5	Hydraulic oil level low	0.5	SS7
KS1	141	01-12-2017	07:00:00	01-12-2017	16:00:00	13.75	Hydraulic hose failed	9	SS7
KS1	142	01-12-2017	18:30:00	01-12-2017	18:50:00	2.5	Cabin door iock problem	0.33	SS9
KS1	143	02-12-2017	00:05:46	02-12-2017	02:30:19	5.26	Electrical breakdown	2.41	SS5
KS1	144	02-12-2017	07:30:00	02-12-2017	11:45:00	4.99	Hydraulic oil leakage	4.25	SS7
KS1	145	03-12-2017	06:15:56	03-12-2017	06:34:44	18.52	Electrical breakdown	0.31	SS5
KS1	146	04-12-2017	12:01:00	04-12-2017	12:55:00	29.44	Diesel leakage	0.9	SS6
KS1	147	04-12-2017	14:40:00	04-12-2017	16:10:20	1.75	Hydraulic oil leakage	1.51	SS7
KS1	148	07-12-2017	05:50:00	07-12-2017	05:55:00	61.66	Tooth point missed	0.08	SS3
KS1	149	07-12-2017	11:50:00	07-12-2017	12:15:00	5.92	A/C not working	0.42	SS5
KS1	150	08-12-2017	12:01:00	08-12-2017	20:30:00	23.77	Bucket crack	8.48	SS3
KS1	151	08-12-2017	20:40:00	08-12-2017	23:30:00	0.17	Hoist operation slow	2.83	SS7
KS1	152	09-12-2017	17:20:00	09-12-2017	19:00:00	17.83	Electrical breakdown	1.67	SS5
KS1	153	12-12-2017	18:45:00	12-12-2017	18:50:00	71.75	Tooth point missed	0.08	SS3
KS1	154	13-12-2017	22:15:00	14-12-2017	05:02:20	27.42	Hydraulic oil leakage	6.79	SS7
KS1	155	15-12-2017	16:00:00	15-12-2017	18:30:00	34.96	Tooth point missed	2.5	SS3

KS1	156	15-12-2017	23:30:00	15-12-2017	23:40:00	5	Tooth point missed	0.17	SS3
KS1	157	16-12-2017	01:30:00	16-12-2017	01:45:00	1.83	Hydraulic oil leakage	0.25	SS7
KS1	158	17-12-2017	17:45:00	17-12-2017	18:15:00	40	Tooth point missed	0.5	SS3
KS1	159	17-12-2017	18:30:00	17-12-2017	18:50:00	0.25	Electrical breakdown	0.33	SS5
KS1	160	18-12-2017	21:45:00	18-12-2017	22:00:00	26.92	Tooth point missed	0.25	SS3
KS1	161	18-12-2017	22:05:00	18-12-2017	22:20:00	0.08	Tooth point missed	0.25	SS3
KS1	162	19-12-2017	06:00:00	19-12-2017	06:40:00	7.67	Engine rpm not raising/lowering	0.67	SS6
KS1	163	19-12-2017	21:35:00	19-12-2017	21:55:00	14.92	Tooth point missed	0.33	SS3
KS1	164	20-12-2017	09:30:00	20-12-2017	11:00:00	11.58	Tooth point missed	1.5	SS3
KS1	165	22-12-2017	21:00:00	22-12-2017	21:30:00	58	Tooth point missed	0.5	SS3
KS1	166	23-12-2017	12:50:00	23-12-2017	15:15:00	15.33	Engine rpm become slow	2.42	SS6
KS1	167	25-12-2017	00:30:00	25-12-2017	01:15:00	33.25	Initial problem (engine not starting)	0.75	SS6
KS1	168	25-12-2017	05:00:00	25-12-2017	11:45:00	3.75	Initial problem (engine not starting)	6.75	SS6
KS1	169	28-12-2017	04:40:00	28-12-2017	10:10:00	64.92	Oil leak from swing gear box	5.5	SS7
KS1	170	28-12-2017	10:40:00	29-12-2017	13:00:00	0.5	Hoist operation slow	26.33	SS7
KS1	171	31-12-2017	23:30:00	01-01-2018	11:45:38	58.5	Water leak from radiator hose / pipe	12.26	SS6
KS1	172	12-01-2018	18:30:00	12-01-2018	23:30:00	270.74	Electrical breakdown	5	SS5
KS1	173	13-01-2018	12:00:00	13-01-2018	21:35:00	12.5	Initial problem (engine not starting)	9.58	SS5
KS1	174	14-01-2018	07:01:00	14-01-2018	11:30:00	9.43	Battery problem	4.48	SS5
KS1	175	15-02-2018	01:45:00	15-02-2018	09:30:00	758.25	Hydraulic hose failed	7.75	SS7
KS1	176	17-02-2018	23:30:00	18-02-2018	00:30:00	62	Wiper fixing	1	SS9
KS1	177	20-03-2018	08:31:00	20-03-2018	10:00:00	728.02	Hydraulic oil leakage	1.48	SS7
KS1	178	22-03-2018	11:45:37	22-03-2018	14:41:49	49.76	Hydraulic hose failed	2.94	SS7
KS1	179	26-03-2018	14:00:00	26-03-2018	20:20:00	95.3	Hydraulic hose failed	6.33	SS7
KS1	180	28-04-2018	20:30:00	29-04-2018	01:40:00	792.17	Hydraulic hose failed	5.17	SS7
KS1	181	30-04-2018	12.15.00	30-04-2018	17.00.42	34.58	Hydraulic hose failed	4.76	SS7
					MTBF of KS1	**43.83**	**MTTR of KS1**	**4.69**	
Systems	**No. of failures**	**Start Date**	**Start Time**	**End date**	**End Time**	**TBF, hrs**	**Reasons**	**TTR, hrs**	**Failure Codes**
KS2	1	31-03-2017	15:00:00	02-04-2017	15:30:00	0	Electrical breakdown	48.5	SS5
KS2	2	03-04-2017	07:01:00	03-04-2017	07:02:00	15.52	Horn/buzzer not working	0.02	SS9
KS2	3	03-04-2017	15:00:00	03-04-2017	20:45:00	7.97	Electrical breakdown	5.75	SS5

KS2	4	03-04-2017	21:15:00	04-04-2017	01:15:01	0.5	Hydraulic oil leakage	4	SS7
KS2	5	04-04-2017	14:00:00	04-04-2017	15:30:00	12.75	Radiator leakage	1.5	SS6
KS2	6	05-04-2017	07:00:00	05-04-2017	11:45:20	15.5	Bucket is cracked	4.76	SS3
KS2	7	06-04-2017	15:30:00	06-04-2017	17:15:00	27.74	Hydraulic oil level low	1.75	SS7
KS2	8	07-04-2017	07:00:00	12-04-2017	00:30:41	13.75	Hydraulic oil leak from hydraulic tank breather	113.51	SS7
KS2	9	12-04-2017	07:30:00	12-04-2017	12:00:00	6.99	Hydraulic oil level low	4.5	SS7
KS2	10	12-04-2017	15:00:00	12-04-2017	18:45:00	3	Hydraulic oil temperature raising	3.75	SS7
KS2	11	12-04-2017	21:30:00	13-04-2017	01:00:22	2.75	Hydraulic hose failed	3.51	SS7
KS2	12	13-04-2017	15:01:00	17-04-2017	19:00:41	14.01	Water temperature raising	99.99	SS6
KS2	13	23-04-2017	18:15:00	23-04-2017	19:10:00	143.24	Tooth point missed	0.92	SS3
KS2	14	24-04-2017	09:10:58	24-04-2017	09:40:27	14.02	Structural cracks/welding joint failed	0.49	SS2
KS2	15	25-04-2017	12:20:46	25-04-2017	12:55:06	26.67	Hydraulic hose failed	0.57	SS7
KS2	16	25-04-2017	17:10:00	25-04-2017	17:40:00	4.25	Tooth point missed	0.5	SS3
KS2	17	27-04-2017	16:55:00	28-04-2017	01:45:00	47.25	Bucket pitch brace pin came out	8.83	SS3
KS2	18	28-04-2017	18:00:46	28-04-2017	18:20:28	16.26	Electrical breakdown	0.33	SS5
KS2	19	03-05-2017	16:30:00	03-05-2017	22:45:00	118.16	Tooth point missed	6.25	SS3
KS2	20	07-05-2017	08:01:00	07-05-2017	12:10:00	81.27	Bucket crack	4.15	SS3
KS2	21	09-05-2017	22:50:58	15-05-2017	19:00:00	58.68	Hydraulic hose failed	140.15	SS7
KS2	22	16-05-2017	10:30:16	16-05-2017	12:00:20	15.5	Hydraulic hose failed	1.5	SS7
KS2	23	17-05-2017	00:10:00	17-05-2017	00:20:00	12.16	Electrical breakdown	0.17	SS5
KS2	24	21-05-2017	02:30:00	21-05-2017	03:30:00	98.17	Horn/buzzer not working	1	SS9
KS2	25	21-05-2017	09:00:01	21-05-2017	11:00:00	5.5	Hydraulic hose failed	2	SS7
KS2	26	22-05-2017	12:55:00	22-05-2017	17:50:00	25.92	Hydraulic oil leakage	4.92	SS7
KS2	27	25-05-2017	11:10:00	25-05-2017	12:15:00	65.33	Engine off in running	1.08	SS6
KS2	28	26-05-2017	05:30:00	26-05-2017	11:10:00	17.25	Bucket pad lock damaged	5.67	SS3
KS2	29	30-05-2017	05:45:00	30-05-2017	09:00:00	90.58	Hydraulic oil leakage	3.25	SS7
KS2	30	31-05-2017	18:00:44	31-05-2017	18:10:33	33.01	Horn problem	0.16	SS5
KS2	31	01-06-2017	10:30:00	01-06-2017	11:55:00	16.32	Electrical breakdown	1.42	SS5
KS2	32	02-06-2017	00:20:00	02-06-2017	04:00:00	12.42	Engine rpm not raising/lowering	3.67	SS6
KS2	33	02-06-2017	09:00:00	02-06-2017	16:30:56	5	Initial problem (engine not starting)	7.52	SS6
KS2	34	03-06-2017	08:25:00	03-06-2017	09:30:00	15.9	Electrical breakdown	1.08	SS5
KS2	35	04-06-2017	07:00:00	04-06-2017	10:40:00	21.5	Engine rpm not raising/lowering	3.67	SS5

KS2	36	05-06-2017	12:01:00	06-06-2017	17:00:00	25.35	Swing motor mounting bolts broken	28.98	SS10
KS2	37	07-06-2017	12:15:00	08-06-2017	04:00:00	19.25	Bucket crack	15.75	SS3
KS2	38	08-06-2017	09:01:10	08-06-2017	10:20:21	5.02	Hydraulic oil leakage	1.32	SS7
KS2	39	10-06-2017	09:00:10	10-06-2017	11:30:00	46.66	Bucket crack	2.5	SS3
KS2	40	14-06-2017	08:30:01	14-06-2017	11:40:00	93	Structural cracks/welding joint failed	3.17	SS2
KS2	41	15-06-2017	07:00:00	15-06-2017	16:00:00	19.33	Catwalk railing damaged	9	SS9
KS2	42	17-06-2017	12:30:00	17-06-2017	21:15:00	44.5	Tooth point adapter missing	8.75	SS3
KS2	43	17-06-2017	21:20:00	17-06-2017	21:35:00	0.08	Problem occurred in operator	0.25	SS9
KS2	44	17-06-2017	22:00:00	17-06-2017	22:20:00	0.42	Water temperature raising	0.33	SS6
KS2	45	18-06-2017	03:30:38	18-06-2017	04:00:32	5.18	Initial problem (engine not starting)	0.5	SS5
KS2	46	18-06-2017	16:00:00	18-06-2017	21:00:00	11.99	Initial problem (engine not starting)	5	SS5
KS2	47	19-06-2017	07:01:00	20-06-2017	17:25:57	10.02	Bucket changing work	34.42	SS3
KS2	48	22-06-2017	09:45:00	22-06-2017	11:45:00	40.32	Engine rpm become slow	2	SS6
KS2	49	23-06-2017	11:50:00	23-06-2017	12:30:00	24.08	Initial problem (engine not starting)	0.67	SS6
KS2	50	23-06-2017	16:00:00	23-06-2017	16:20:36	3.5	Initial problem (engine not starting)	0.34	SS6
KS2	51	24-06-2017	09:15:00	24-06-2017	18:00:00	16.91	Swing problem	8.75	SS10
KS2	52	27-06-2017	04:00:00	27-06-2017	04:10:00	58	Electrical breakdown	0.17	SS5
KS2	53	27-06-2017	05:15:00	27-06-2017	05:20:00	1.08	Electrical breakdown	0.08	SS5
KS2	54	28-06-2017	15:30:00	28-06-2017	17:45:00	34.17	Engine rpm not raising/lowering	2.25	SS6
KS2	55	29-06-2017	17:15:00	29-06-2017	18:20:00	23.5	Engine rpm become slow	1.08	SS6
KS2	56	03-07-2017	07:00:00	03-07-2017	07:00:01	84.67	Engine rpm become slow		SS6
KS2	57	03-07-2017	12:00:00	04-07-2017	12:00:00	5	Hydraulic oil leakage	24	SS7
KS2	58	05-07-2017	17:10:00	05-07-2017	17:30:00	29.17	Wiper fixing	0.33	SS9
KS2	59	06-07-2017	16:30:00	06-07-2017	16:45:00	23	Initial problem (engine not starting)	0.25	SS6
KS2	60	12-07-2017	08:00:00	12-07-2017	12:15:00	135.25	Catwalk railing damaged	4.25	SS9
KS2	61	12-07-2017	12:25:00	12-07-2017	13:00:00	0.17	Initial problem (engine not starting)	0.58	SS6
KS2	62	16-07-2017	13:45:17	16-07-2017	17:20:00	96.75	Hydraulic hose failed	3.58	SS7
KS2	63	17-07-2017	23:30:00	18-07-2017	00:30:00	30.17	Wiper fixing	1	SS9
KS2	64	21-07-2017	01:00:00	21-07-2017	01:15:00	72.5	Hydraulic oil temperature raising	0.25	SS7
KS2	65	21-07-2017	15:00:00	27-07-2017	09:15:00	13.75	Initial problem (engine not starting)	138.25	SS6
KS2	66	27-07-2017	09:40:00	27-07-2017	13:15:00	0.42	Initial problem (engine not starting)	3.58	SS5
KS2	67	29-07-2017	15:01:00	29-07-2017	16:30:00	49.77	Initial problem (engine not starting)	1.48	SS5

KS2	68	29-07-2017	18:50:00	29-07-2017	22:25:00	2.33	Hydraulic hose failed	3.58	SS7
KS2	69	30-07-2017	09:45:00	30-07-2017	13:00:00	11.33	Hoist operation slow	3.25	SS7
KS2	70	31-07-2017	09:15:00	31-07-2017	09:45:00	20.25	Initial problem (engine not starting)	0.5	SS6
KS2	71	31-07-2017	12:30:00	31-07-2017	12:35:00	2.75	A/C not working	0.08	SS6
KS2	72	01-08-2017	12:45:00	01-08-2017	13:30:00	24.17	Hydraulic oil temperature raising	0.75	SS7
KS2	73	02-08-2017	01:00:00	02-08-2017	01:30:00	11.5	Head lights problem	0.5	SS5
KS2	74	02-08-2017	15:30:45	02-08-2017	18:45:58	14.01	Hydraulic oil temperature raising	3.25	SS7
KS2	75	02-08-2017	23:00:00	03-08-2017	00:45:00	4.23	Hydraulic oil temperature raising	1.75	SS7
KS2	76	04-08-2017	14:40:00	04-08-2017	17:00:52	37.92	Hydraulic oil leakage	2.35	SS7
KS2	77	05-08-2017	12:15:00	06-08-2017	13:15:54	19.24	Hydraulic oil leakage	25.02	SS7
KS2	78	07-08-2017	01:30:00	07-08-2017	02:00:00	12.24	Initial problem (engine not starting)	0.5	SS6
KS2	79	08-08-2017	01:00:00	08-08-2017	01:30:00	23	Initial problem (engine not starting)	0.5	SS6
KS2	80	08-08-2017	21:00:00	09-08-2017	00:30:00	19.5	Propel problem	3.5	SS10
KS2	81	12-08-2017	18:20:00	12-08-2017	20:40:00	89.83	Engine rpm become slow	2.33	SS6
KS2	82	20-08-2017	14:30:00	20-08-2017	19:00:00	185.83	Hydraulic oil leakage	4.5	SS7
KS2	83	21-08-2017	08:31:00	21-08-2017	09:30:00	13.52	Tooth point worn out	0.98	SS3
KS2	84	21-08-2017	09:50:00	21-08-2017	11:40:00	0.33	Swing brake problem	1.83	SS10
KS2	85	25-08-2017	12:30:00	25-08-2017	12:45:00	96.83	A/C not working	0.25	SS5
KS2	86	26-08-2017	09:01:00	26-08-2017	14:15:00	20.27	A/C not working	5.23	SS5
KS2	87	29-08-2017	13:20:00	29-08-2017	17:15:00	71.08	Hoist cylinder hose failure	3.92	SS7
KS2	88	30-08-2017	04:30:00	30-08-2017	11:50:49	11.25	Hydraulic oil leakage	7.35	SS7
KS2	89	02-09-2017	21:35:00	02-09-2017	22:40:00	81.74	Structural cracks/welding joint failed	1.08	SS2
KS2	90	09-09-2017	17:15:00	09-09-2017	18:45:00	162.58	Tooth point missed	1.5	SS3
KS2	91	10-09-2017	02:50:13	10-09-2017	03:50:48	8.09	Wiper fixing	1.01	SS9
KS2	92	10-09-2017	05:15:41	10-09-2017	05:50:33	1.41	Wiper fixing	0.58	SS9
KS2	93	11-09-2017	07:00:00	11-09-2017	10:00:00	25.16	Hydraulic hose failed	3	SS7
KS2	94	19-09-2017	07:00:36	19-09-2017	12:10:46	189.01	Bucket hinge pin came out	5.17	SS3
KS2	95	19-09-2017	19:50:00	20-09-2017	04:00:00	7.65	Hydraulic hose failed	8.17	SS7
KS2	96	20-09-2017	08:31:05	21-09-2017	18:00:00	4.52	Bucket lift cylinder failed	33.48	SS7
KS2	97	25-09-2017	07:00:00	26-09-2017	10:00:00	85	Bucket changing work	27	SS3
KS2	98	01-10-2017	10:50:00	01-10-2017	15:50:31	120.83	A/C not working	5.01	SS5
KS2	99	01-10-2017	16:50:41	01-10-2017	18:30:40	1	A/C not working	1.67	SS5

KS2	100	04-10-2017	11:35:00	04-10-2017	14:50:00	65.07	Bucket hinge pin came out	3.25	SS3
KS2	101	08-10-2017	01:30:00	08-10-2017	04:45:00	82.67	Swing brake problem	3.25	SS10
KS2	102	09-10-2017	00:50:00	09-10-2017	12:20:17	20.08	Engine rpm not raising/lowering	11.5	SS6
KS2	103	13-10-2017	01:00:00	13-10-2017	01:30:00	84.66	Head lights problem	0.5	SS5
KS2	104	14-10-2017	20:40:00	15-10-2017	01:30:00	43.17	Water leak from radiator hose / pipe	4.83	SS5
KS2	105	15-10-2017	01:45:00	15-10-2017	15:30:00	0.25	Track cut in transmission	13.75	SS10
KS2	106	16-10-2017	09:45:00	16-10-2017	13:25:00	18.25	No water in radiator	3.67	SS6
KS2	107	17-10-2017	03:45:19	17-10-2017	04:20:18	14.34	Initial problem (engine not starting)	0.58	SS5
KS2	108	19-10-2017	13:20:00	19-10-2017	13:50:00	57	Hydraulic oil temperature raising	0.5	SS7
KS2	109	20-10-2017	17:50:00	20-10-2017	18:10:00	28	Initial problem (engine not starting)	0.33	SS6
KS2	110	21-10-2017	18:10:00	21-10-2017	18:30:00	24	Tooth point missed	0.33	SS3
KS2	111	25-10-2017	08:01:00	25-10-2017	11:40:00	85.52	Problem occurred in power tong	3.65	SS10
KS2	112	25-10-2017	23:30:00	26-10-2017	00:30:00	11.83	Head lights problem	1	SS5
KS2	113	26-10-2017	02:40:00	26-10-2017	04:10:00	2.17	Head lights problem	1.5	SS5
KS2	114	26-10-2017	10:30:00	26-10-2017	14:50:00	6.33	Hydraulic oil leakage	4.33	SS7
KS2	115	29-10-2017	05:00:00	29-10-2017	06:00:00	62.17	Hydraulic hose failed	1	SS7
KS2	116	31-10-2017	02:15:00	31-10-2017	02:20:00	44.25	Tooth point missed	0.08	SS3
KS2	117	31-10-2017	16:00:00	31-10-2017	18:45:00	13.67	A/C not working	2.75	SS5
KS2	118	04-11-2017	09:00:52	04-11-2017	15:45:00	86.26	Hydraulic oil leakage	6.74	SS7
KS2	119	08-11-2017	17:45:00	08-11-2017	18:00:00	98	A/C not working	0.25	SS5
KS2	120	12-11-2017	19:50:21	12-11-2017	20:45:37	97.84	Hydraulic oil leakage	0.92	SS7
KS2	121	14-11-2017	09:40:00	14-11-2017	09:55:00	36.91	A/C not working	0.25	SS5
KS2	122	18-11-2017	08:45:00	18-11-2017	08:50:00	94.83	Cabin door lock problem	0.08	SS9
KS2	123	18-11-2017	10:50:00	19-11-2017	18:30:00	2	A/C not working	31.67	SS5
KS2	124	20-11-2017	18:30:00	20-11-2017	20:40:00	24	Engine rpm not raising/lowering	2.17	SS6
KS2	125	21-11-2017	12:01:00	21-11-2017	14:30:00	15.35	Hydraulic hose failed	2.48	SS7
KS2	126	22-11-2017	16:00:00	22-11-2017	16:45:00	25.5	Tooth point missed	0.75	SS3
KS2	127	22-11-2017	23:40:00	23-11-2017	23:15:00	6.92	Hydraulic oil leakage	23.58	SS7
KS2	128	24-11-2017	19:30:00	24-11-2017	22:15:00	20.25	Bucket hinge pin came out	2.75	SS3
KS2	129	25-11-2017	16:00:00	25-11-2017	16:45:00	17.75	Grease hose failed	0.75	SS7
KS2	130	26-11-2017	10:25:00	26-11-2017	13:45:00	17.67	Hydraulic oil leakage	3.33	SS7
KS2	131	26-11-2017	14:50:00	26-11-2017	18:00:00	1.08	Hydraulic oil leakage	3.17	SS7

KS2	132	27-11-2017	15:40:00	27-11-2017	17:00:00	21.67	Hydraulic oil level low	1.33	SS7
KS2	133	27-11-2017	18:25:00	27-11-2017	18:45:00	1.42	Hydraulic oil leakage	0.33	SS7
KS2	134	27-11-2017	21:00:00	27-11-2017	21:45:00	2.25	Electrical breakdown	0.75	SS5
KS2	135	05-12-2017	01:45:00	06-12-2017	13:30:00	172	Bucket hinge pin came out	35.75	SS3
KS2	136	06-12-2017	13:31:00	06-12-2017	13:45:00	0.02	Electrical breakdown	0.23	SS5
KS2	137	07-12-2017	07:30:00	07-12-2017	08:15:00	17.75	Initial problem (engine not starting)	0.75	SS5
KS2	138	08-12-2017	08:01:00	08-12-2017	08:10:00	23.77	Cabin door lock problem	0.15	SS9
KS2	139	13-12-2017	14:11:00	13-12-2017	21:15:00	126.02	Electrical breakdown	7.07	SS5
KS2	140	15-12-2017	23:30:00	15-12-2017	23:45:00	50.25	Cabin door lock problem	0.25	SS9
KS2	141	16-12-2017	09:10:30	16-12-2017	14:00:00	9.43	Tract failure in transmission	4.83	SS10
KS2	142	16-12-2017	19:55:00	17-12-2017	00:30:00	5.92	No water in radiator	4.58	SS6
KS2	143	22-12-2017	03:30:11	22-12-2017	03:45:01	123	Horn problem	0.25	SS5
KS2	144	27-12-2017	16:10:08	27-12-2017	16:55:11	132.42	Tooth point missed	0.75	SS3
KS2	145	27-12-2017	21:00:35	27-12-2017	21:30:34	4.09	Tooth point missed	0.5	SS3
KS2	146	29-12-2017	09:30:00	29-12-2017	12:00:00	35.99	Hydraulic hose failed	2.5	SS7
KS2	147	30-12-2017	00:45:00	30-12-2017	02:45:00	12.75	Hydraulic hose failed	2	SS7
KS2	148	30-12-2017	17:30:00	30-12-2017	21:50:00	14.75	Electrical breakdown	4.33	SS5
KS2	149	31-12-2017	07:00:54	31-12-2017	08:45:41	9.18	Electrical breakdown	1.75	SS5
KS2	150	02-01-2018	00:05:46	02-01-2018	02:30:19	39.33	Electrical breakdown	2.41	SS5
KS2	151	02-01-2018	07:30:00	02-01-2018	11:45:00	4.99	Hydraulic oil leakage	4.25	SS7
KS2	152	03-02-2018	06:15:56	03-02-2018	06:34:44	762.52	Electrical breakdown	0.31	SS5
KS2	153	04-02-2018	12:01:00	04-02-2018	12:55:00	29.44	Diesel leakage	0.9	SS6
KS2	154	04-03-2018	14:40:00	04-03-2018	16:10:20	673.75	Hydraulic oil leakage	1.51	SS7
KS2	155	07-03-2018	05:50:00	07-03-2018	05:55:00	61.66	Tooth point missed	0.08	SS3
KS2	156	07-03-2018	11:50:00	07-03-2018	12:15:00	5.92	A/C not working	0.42	SS5
KS2	157	08-04-2018	12:01:00	08-04-2018	20:30:00	767.77	Bucket crack	8.48	SS3
					MTBF of KS2	**49.57**	**MTTR of KS2**	**7.48**	
Systems	**No. of failures**	**Start Date**	**Start Time**	**End date**	**End Time**	**TBF, hrs**	**Reasons**	**TTR, hrs**	**Failure Codes**
BD3	1	15-02-2015	10.52.30	19-02-2015	07.00.00	0	Parking brake not functioning properly	85.125	DS1
BD3	2	25-02-2015	09.10.53	01-03-2015	23.00.00	146.18	Steering hard	109.82	DS7
BD3	3	15-03-2015	09.37.48	15-03-2015	15.33.54	322.63	Electrical breakdown	5.93	DS4

BD3	4	20-03-2015	11.25.52	20-03-2015	14.00.00	115.87	Battery terminal missing	2.57	DS4
BD3	5	01-04-2015	08.39.50	30-05-2015	15.00.00	282.66	Engine oil throw from breather	822.34	DS5
BD3	6	05-06-2015	13.37.36	20-06-2015	10.03.00	142.63	Hydraulic oil leakage in brakes	20.42	DS1
BD3	7	05-07-2015	07.30.00	17-06-2015	17.12.03	357.45	Steering hard	3	DS7
BD3	8	05-07-2015	23.30.43	06-07-2015	09.00.00	438.31	Air leakage	9.49	DS1
BD3	9	10-07-2015	19.30.00	11-07-2015	11.12.29	106.5	Water leak from radiator hose / pipe	15.71	DS5
BD3	10	15-07-2015	23.15.00	16-07-2015	11.24.27	108.04	Hoist hydraulic piping leakage in steering	12.16	DS7
BD3	11	21-07-2015	01.00.00	21-07-2015	14.00.00	109.59	Hoist hydraulic piping leakage in steering	13	DS7
BD3	12	25-07-2015	04.00.00	25-07-2015	05.00.00	86	Steering hard	1	DS4
BD3	13	27-07-2015	18.00.00	28-07-2015	14.22.42	61	Hoist hydraulic piping leakage engine	20.38	DS5
BD3	14	29-07-2015	18.30.00	30-07-2015	09.37.54	28.12	Hoist hydraulic piping leakage engine	15.13	DS5
BD3	15	31-07-2015	18.00.00	01-08-2015	14.22.17	32.37	Transmission, convertor gears not engage	20.37	DS10
BD3	16	07-08-2015	07.30.25	07-08-2015	10.08.44	137.14	Tyre O-ring failed	2.64	DS2
BD3	17	09-08-2015	06.50.00	09-08-2015	08.00.00	44.69	Steering hard	1.17	DS7
BD3	18	14-08-2015	20.00.39	15-08-2015	09.33.57	132.01	Steering hard	13.56	DS7
BD3	19	17-08-2015	09.30.00	17-08-2015	14.47.03	47.93	Steering hard	5.28	DS7
BD3	20	18-08-2015	07.05.00	18-08-2015	09.30.00	16.3	Steering hard	2.42	DS7
BD3	21	18-08-2015	11.55.00	18-08-2015	14.41.35	2.42	Steering hard	2.78	DS7
BD3	22	25-08-2015	06.20.00	25-08-2015	13.43.57	159.64	Hydraulic oil leakage in brakes	7.4	DS1
BD3	23	05-09-2015	03.30.00	05-09-2015	04.00.00	253.77	Head lights problem	0.5	DS4
BD3	24	08-09-2015	10.30.00	08-09-2015	13.28.02	78.5	Suspension weak	2.97	DS6
BD3	25	10-09-2015	08.30.00	10-09-2015	09.30.00	43.03	No water in radiator	1	DS5
BD3	26	15-09-2015	17.30.00	16-09-2015	11.31.53	128	Suspension oil leakage	18.03	DS6
BD3	27	18-09-2015	12.00.00	18-09-2015	15.30.55	48.47	Suspension weak	3.52	DS6
BD3	28	19-09-2015	00.30.00	19-09-2015	14.00.00	8.98	Suspension weak	13.5	DS6
BD3	29	22-09-2015	15.30.00	23-09-2015	11.00.00	73.5	Suspension weak	19.5	DS6
BD3	30	23-09-2015	18.00.00	25-09-2015	13.14.38	7	Suspension weak	43.24	DS6
BD3	31	06-10-2015	10.00.00	06-10-2015	14.00.00	260.76	Bucket hoisting problem	4	DS6
BD3	32	11-10-2015	19.20.00	11-10-2015	19.35.00	125.33	Head lights problem	0.25	DS4
BD3	33	13-10-2015	21.30.00	13-10-2015	22.00.01	49.92	Lighting problem	0.5	DS4
BD3	34	14-10-2015	06.30.00	14-10-2015	07.45.25	8.5	Electrical breakdown	1.26	DS4
BD3	35	28-10-2015	01.00.00	28-10-2015	01.20.00	329.24	Head lights problem	0.33	DS4

BD3	36	28-10-2015	09.00.00	28-10-2015	13.00.00	7.67	Brake oil leakage	4	DS1
BD3	37	01-11-2015	12.12.00	01-11-2015	13.30.00	95.2	Parking brake not functioning properly	1.3	DS1
BD3	38	18-11-2015	16.00.00	18-11-2015	16.30.00	410.5	Radiator leakage	0.5	DS4
BD3	39	22-11-2015	11.15.00	22-11-2015	14.30.00	90.75	Brake oil leakage	3.25	DS1
BD3	40	24-11-2015	07.15.00	26-11-2015	14.00.00	40.75	Water leak from water pump seal	54.75	DS4
BD3	41	28-11-2015	07.30.00	28-12-2015	08.00.00	41.5	Electrical breakdown	0.5	DS4
BD3	42	28-12-2015	10.00.00	14-12-2015	11.26.36	2	Air not building up to support engine to support engine	1.44	DS1
BD3	43	20-12-2015	15.30.00	21-12-2015	14.42.38	148.06	Water leak from radiator hose / pipe	23.21	DS1
BD3	44	25-12-2015	02.00.00	25-12-2015	09.30.18	83.29	Transmission, convertor gears not upshift	7.5	DS10
BD3	45	28-12-2015	02.00.00	28-12-2015	11.00.23	64.5	Engine oil level low	9.01	DS4
BD3	46	30-12-2015	06.50.00	30-12-2015	11.00.56	43.83	Brakes weak	4.18	DS1
BD3	47	03-01-2016	09.00.00	03-01-2016	15.36.20	93.98	Air leakage	6.61	DS1
BD3	48	06-01-2016	20.00.18	07-01-2016	13.32.10	76.4	Hydraulic hose failed in brake	17.53	DS1
BD3	49	07-01-2016	19.00.00	08-01-2016	10.45.00	5.46	Electrical breakdown	15.75	DS4
BD3	50	14-01-2016	03.00.00	15-01-2016	14.00.00	136.25	Hydraulic oil leakage in suspension	35	DS6
BD3	51	15-01-2016	14.54.12	31-01-2016	08.24.48	0.9	Hydraulic oil leakage in suspension	377.51	DS6
BD3	52	01-02-2016	08.25.54	01-02-2016	14.29.37	24.02	Transmission, convertor front drive line	6.06	DS10
BD3	53	02-02-2016	22.25.00	03-02-2016	14.25.06	31.92	Electrical breakdown	16	DS4
BD3	54	16-02-2016	19.00.01	17-02-2016	13.27.00	316.58	Steering hard	6	DS7
BD3	55	23-02-2016	08.23.00	24-02-2016	13.45.12	138.93	Suspension weak	16.8	DS6
BD3	56	25-02-2016	11.30.00	25-02-2016	13.40.00	21.75	Battery terminal missing	2.17	DS4
					MTBF of BD3	**110.12**	**MTTR of BD3**	**34.095**	
Systems	**No. of failures**	**Start Date**	**Start Time**	**End date**	**End Time**	**TBF, hrs**	**Reasons**	**TTR, hrs**	**Failure Codes**
BD4	1	02-01-2015	10:19:19	02-01-2015	13:00:00	0	A/C not working	2.68	DS4
BD4	2	21-01-2015	09:31:13	21-01-2015	14:55:00	452.52	Brakes weak	5.4	DS1
BD4	3	13-02-2015	10:23:00	14-03-2015	09:00:00	547.47	Hydraulic oil leakage in suspension	23.7	DS6
BD4	4	23-03-2015	08:21:07	24-03-2015	12:05:00	215.35	Electrical breakdown	6	DS4
BD4	5	16-04-2015	03:09:00	17-06-2015	14:54:12	567.07	Convertor transmission oil	11.25	DS10
BD4	6	02-07-2015	09:34:40	02-07-2015	12:08:57	354.67	Battery weak starting problem	2.57	DS10
BD4	7	03-07-2015	23:00:00	03-07-2015	24:00:00	34.85	Steering hard	2	DS7
BD4	8	05-07-2015	18:40:00	05-07-2015	18:50:00	42.67	Engine not getting off	0.17	DS5

BD4	9	09-07-2015	16:30:00	24-07-2015	14:00:00	93.67	Hoist cylinder hose failure	357.5	DS6
BD4	10	24-07-2015	14:52:16	25-07-2015	14:12:35	0.87	Hydraulic oil leakage	23.34	DS6
BD4	11	25-07-2015	19:00:11	25-07-2015	19:15:33	4.79	O-ring failure	0.26	DS6
BD4	12	29-07-2015	12:00:25	29-07-2015	13:46:01	88.75	Retarder valve got struck up	1.76	DS1
BD4	13	30-07-2015	10:15:00	30-07-2015	13:28:04	20.48	Air hose failed	3.22	DS1
BD4	14	30-07-2015	18:00:00	31-07-2015	11:41:12	4.53	Air hose failed	17.69	DS1
BD4	15	31-07-2015	18:00:00	07-08-2015	10:10:42	6.31	Fire suppression system problem	160.18	DS4
BD4	16	07-08-2015	23:15:00	08-08-2015	14:00:00	13.07	No cabin fan	14.75	DS4
BD4	17	09-08-2015	07:12:33	09-08-2015	13:41:31	17.21	Tyre O-ring failed	6.48	DS2
BD4	18	10-08-2015	15:01:00	12-08-2015	14:15:00	25.32	Fire suppression system problem	47.23	DS4
BD4	19	12-08-2015	15:00:00	13-08-2015	14:30:00	0.75	Fire suppression system problem	23.5	DS4
BD4	20	18-08-2015	10:30:00	19-08-2015	14:00:00	116	Air leakage	27.5	DS1
BD4	21	20-08-2015	09:00:00	20-08-2015	13:34:36	19	Air leakage	4.58	DS1
BD4	22	26-08-2015	07:30:00	26-08-2015	10:33:19	137.92	Oil leakage on differential unit	3.06	DS2
BD4	23	05-09-2015	09:00:00	05-09-2015	14:30:00	238.44	Electrical breakdown	5.5	DS4
BD4	24	08-09-2015	09:00:00	08-09-2015	14:05:08	66.5	Brakes weak	5.09	DS1
BD4	25	17-09-2015	06:30:05	17-09-2015	14:30:00	208.42	Oil leakage in steering	8	DS7
BD4	26	18-09-2015	07:00:00	23-09-2015	14:30:08	16.5	Hydraulic oil leakage in steering	127.5	DS7
BD4	27	01-10-2015	12:12:43	01-10-2015	12:23:16	189.71	Hoist operation slow	0.18	DS5
BD4	28	01-10-2015	13:00:00	01-10-2015	13:15:00	0.61	Battery weak starting problem	0.25	DS4
BD4	29	02-11-2015	10:49:01	02-11-2015	10:49:27	765.57	Oil leakage in differential unit	0.01	DS2
BD4	30	02-11-2015	10:52:10	02-11-2015	10:52:25	0.05	Cylinder leakage in steering hydraulic part	6	DS7
BD4	31	02-11-2015	10:58:24	02-11-2015	11:06:23	0.1	A/C not working	0.13	DS4
BD4	32	02-11-2015	13:30:00	03-11-2015	14:00:50	2.39	Hydraulic oil leakage in suspension	24.51	DS6
BD4	33	24-11-2015	09:45:00	24-11-2015	14:00:00	499.74	Brakes weak	4.25	DS1
BD4	34	01-12-2015	09:30:00	01-12-2015	14:00:24	163.5	Gears not engaging	4.51	DS10
BD4	35	03-12-2015	09:57:20	03-12-2015	14:36:49	43.95	A/C not working	4.66	DS4
BD4	36	03-12-2015	18:00:00	03-12-2015	21:00:00	3.39	A/C not working	3	DS4
BD4	37	04-12-2015	09:00:00	04-12-2015	14:53:40	12	Oil leakage in suspension cylinder	5.89	DS6
BD4	38	04-12-2015	23:00:00	05-12-2015	14:39:10	8.11	Tyre O-ring failed	15.65	DS2
BD4	39	11-12-2015	07:00:00	12-12-2015	13:30:00	136.35	Hydraulic oil leakage	30.5	DS6
BD4	40	18-12-2015	08:30:00	18-12-2015	14:30:25	139	Diesel leakage due to hose pipe failure at engine	6.01	DS5

BD4	41	18-12-2015	15:00:00	19-12-2015	14:00:00	0.49	Hydraulic oil leakage	23	DS6
BD4	42	21-12-2015	07:30:00	07-01-2016	13:37:18	41.5	Steering hard	414.12	DS7
BD4	43	08-01-2016	17:38:19	09-01-2016	10:30:00	28.02	Transmission, convertor transmission oil	16.86	DS10
BD4	44	16-01-2016	07:30:00	16-01-2016	15:30:04	165	Hydraulic oil leakage	8	DS6
BD4	45	27-01-2016	15:45:00	28-01-2016	13:30:00	264.25	Steering hard	21.75	DS7
BD4	46	31-01-2016	19:00:00	01-02-2016	14:56:43	77.5	Engine rpm not raising/lowering	19.95	DS5
					MTBF of BD4	**126.83**	**MTTR of BD4**	**32.612**	
Systems	**No. of failures**	**Start Date**	**Start Time**	**End date**	**End Time**	**TBF, hrs**	**Reasons**	**TTR, hrs**	**Failure Codes**
BD5	1	02-01-2015	14:40:02	02-01-2015	14:50:00	0	Head lights problem	0.17	DS4
BD5	2	21-01-2015	10:17:14	21-01-2015	14:25:00	451.45	Suspension hammering	4.13	DS6
BD5	3	24-01-2015	09:17:19	24-01-2015	14:23:35	66.87	Suspension weak	5.1	DS6
BD5	4	27-01-2015	22:00:00	28-02-2015	07:00:00	79.61	Cabin vibration	9	DS8
BD5	5	16-03-2015	07:54:54	18-03-2015	09:00:00	384.92	Engine rpm not raising/lowering	1.09	DS5
BD5	6	20-03-2015	07:38:27	20-03-2015	13:45:08	46.64	Electrical breakdown	6.11	DS4
BD5	7	30-03-2015	08:11:37	28-05-2015	07:00:00	234.44	Transmission, convertor transmission oil	670.81	DS10
BD5	8	02-06-2015	11:33:32	02-06-2015	12:00:00	124.56	Air not building up to support engine	0.44	DS10
BD5	9	11-06-2015	09:22:43	23-06-2015	12:00:00	213.38	Steering cylinder oil leakage	2.62	DS7
BD5	10	08-07-2015	08:15:00	08-07-2015	13:15:00	356.25	Air leakage	5	DS10
BD5	11	16-07-2015	15:30:00	16-07-2015	16:00:00	194.25	Radiator leakage	0.5	DS5
BD5	12	16-07-2015	22:00:00	17-07-2015	13:30:00	6	Air hose failed	15.5	DS10
BD5	13	17-07-2015	15:15:00	19-07-2015	11:18:15	1.75	Air hose failed	44.05	DS10
BD5	14	28-07-2015	10:00:42	28-07-2015	14:00:40	214.71	Exhaust smoke is black	4	DS5
BD5	15	29-07-2015	01:30:00	23-09-2015	14:11:27	11.49	Excess blow bye	324.69	DS5
BD5	16	13-10-2015	12:30:00	14-10-2015	14:00:00	478.31	Hydraulic oil leakage	25.5	DS6
BD5	17	21-10-2015	07:34:27	24-10-2015	11:49:35	161.57	Hydraulic oil leakage	76.25	DS6
BD5	18	26-10-2015	23:00:00	27-10-2015	14:00:00	59.17	Air leakage	15	DS10
BD5	19	27-10-2015	15:30:00	29-10-2015	10:49:51	1.5	Electrical breakdown	43.33	DS4
BD5	20	02-11-2015	11:30:00	02-11-2015	13:00:00	96.67	Air leakage	1.5	DS10
BD5	21	04-11-2015	19:30:00	10-11-2015	14:50:00	54.5	Air leakage	19.33	DS10
BD5	22	28-11-2015	11:00:00	28-11-2015	12:20:56	428.17	Air not building up to support engine	1.35	DS10
BD5	23	01-12-2015	11:17:55	01-12-2015	14:33:35	70.95	A/C not working	3.26	DS8

BD5	24	02-12-2015	09:21:40	02-12-2015	10:30:13	18.8	A/C not working	1.14	DS8
BD5	25	04-12-2015	19:00:00	04-12-2015	20:00:00	56.5	Initial problem (engine not starting)	1	DS5
BD5	26	05-12-2015	07:45:00	06-12-2015	14:34:25	11.75	Air leakage	30.82	DS10
BD5	27	15-12-2015	07:00:00	15-12-2015	12:23:07	208.43	Tyre got damaged	5.39	DS2
BD5	28	25-12-2015	18:00:00	26-12-2015	08:12:45	245.61	Engine coolant leaking	14.21	DS5
BD5	29	04-01-2016	01:00:00	04-01-2016	07:17:40	208.79	Bucket hoisting problem	6.29	DS6
BD5	30	05-01-2016	01:00:00	05-01-2016	01:10:00	17.71	Air leakage	0.17	DS10
BD5	31	07-01-2016	10:30:00	07-01-2016	14:35:55	57.33	Air not building up to support engine	4.1	DS10
BD5	32	10-01-2016	17:00:00	11-01-2016	14:33:50	74.4	Engine oil leakage	21.56	DS6
BD5	33	19-01-2016	09:00:00	19-01-2016	13:00:00	186.44	Air not building up to support engine	4	DS10
BD5	34	21-01-2016	11:58:01	21-01-2016	14:30:00	46.97	Air not building up to support engine	2.53	DS10
BD5	35	21-01-2016	18:30:00	23-01-2016	14:00:00	4	Air not building up to support engine	43.5	DS10
BD5	36	24-01-2016	12:30:00	27-01-2016	11:18:27	22.5	Air leakage	70.81	DS10
BD5	37	28-01-2016	15:00:00	28-01-2016	23:30:50	27.69	Hoist problem	8.51	DS5
BD5	38	03-02-2016	18:00:00	04-02-2016	11:39:13	138.49	Hydraulic oil leakage	17.65	DS6
BD5	39	10-02-2016	14:26:00	11-02-2016	14:00:00	146.78	Hydraulic oil leakage	23.57	DS6
BD5	40	11-02-2016	14:42:42	11-02-2016	15:12:09	0.71	Abnormal sound from engine	0.49	DS5
BD5	41	12-02-2016	14:00:00	25-03-2016	14:00:00	22.8	Initial problem (engine not starting)	26	DS5
					MTBF of BD5	**127.63**	**MTTR of BD5**	**38.06**	
Systems	**No. of failures**	**Start Date**	**Start Time**	**End date**	**End Time**	**TBF, hrs**	**Reasons**	**TTR, hrs**	**Failure Codes**
BD6	1	21-01-2015	10:03:51	21-01-2015	14:25:00	0	Brake oil hose failed	4.35	DS1
BD6	2	22-01-2015	11:29:38	22-01-2015	12:00:00	21.08	Electrical breakdown	0.51	DS4
BD6	3	30-01-2015	09:50:04	02-03-2015	13:34:34	189.83	Brakes not releasing	3.74	DS1
BD6	4	05-03-2015	13:39:46	10-05-2015	14:05:57	72.09	Hydraulic oil leakage	0.44	DS6
BD6	5	15-05-2015	11:12:40	30-06-2015	15:32:36	117.11	Hoist operation slow	4.33	DS5
BD6	6	04-07-2015	02:00:00	04-07-2015	03:14:45	82.46	Transmission, convertor gears not upshift	1.25	DS10
BD6	7	06-07-2015	01:46:36	13-07-2015	14:00:00	46.53	Tyre O-ring failed	180.22	DS2
BD6	8	14-07-2015	18:30:00	15-07-2015	12:41:06	28.5	Hydraulic hose failed	18.18	DS6
BD6	9	17-07-2015	05:00:00	17-07-2015	11:05:16	40.32	Air hose failed	6.09	DS1
BD6	10	17-07-2015	18:00:00	17-07-2015	18:30:00	6.91	Air hose failed	0.5	DS1
BD6	11	17-07-2015	23:20:00	18-07-2015	01:00:00	4.83	Air leakage	1.67	DS1

BD6	12	20-07-2015	10:00:00	20-07-2015	11:00:00	57	Initial problem (engine not starting)	1	DS5
BD6	13	20-07-2015	16:02:51	21-07-2015	14:30:22	5.05	Air leakage	22.46	DS2
BD6	14	28-07-2015	11:00:26	28-07-2015	13:30:11	164.5	Electrical breakdown	2.5	DS4
BD6	15	29-07-2015	00:30:00	29-07-2015	14:16:59	11	Initial problem (engine not starting)	13.78	DS5
BD6	16	30-07-2015	09:00:00	30-07-2015	13:05:43	18.72	Gears not engaging	4.1	DS4
BD6	17	31-07-2015	07:30:27	31-07-2015	11:30:04	18.41	Initial problem (engine not starting)	3.99	DS5
BD6	18	03-08-2015	07:30:00	03-08-2015	14:30:00	68	Initial problem (engine not starting)	7	DS5
BD6	19	05-08-2015	23:00:08	06-08-2015	11:41:42	56.5	Air hose failed	12.69	DS1
BD6	20	08-08-2015	07:01:19	08-08-2015	14:00:00	43.33	Transmission	6.98	DS10
BD6	21	09-08-2015	02:00:36	09-08-2015	08:00:00	12.01	Initial problem (engine not starting)	5.99	DS4
BD6	22	10-08-2015	21:50:18	11-08-2015	09:35:10	37.84	Initial problem (engine not starting)	11.75	DS5
BD6	23	18-08-2015	11:00:00	18-08-2015	14:44:17	169.41	Initial problem (engine not starting)	3.74	DS5
BD6	24	07-09-2015	09:00:03	08-09-2015	13:27:32	474.26	Initial problem (engine not starting)	28.46	DS5
BD6	25	22-09-2015	16:30:00	23-09-2015	14:00:52	339.04	Initial problem (engine not starting)	21.51	DS5
BD6	26	28-09-2015	09:30:11	28-09-2015	14:58:36	115.49	Gears not engaging	5.47	DS4
BD6	27	29-09-2015	07:00:00	29-09-2015	12:00:10	16.02	Initial problem (engine not starting)	5	DS5
BD6	28	29-09-2015	14:14:26	30-09-2015	14:29:13	2.24	Initial problem (engine not starting)	24.25	DS5
BD6	29	14-10-2015	06:00:00	14-10-2015	14:00:00	327.51	Initial problem (engine not starting)	8	DS5
BD6	30	17-10-2015	07:30:00	17-10-2015	14:00:00	65.5	Initial problem (engine not starting)	6.5	DS5
BD6	31	24-10-2015	15:01:00	25-10-2015	14:00:00	169.02	Hydraulic hose failed	22.98	DS6
BD6	32	27-10-2015	15:30:00	28-10-2015	13:00:00	49.5	Electrical breakdown	21.5	DS4
BD6	33	01-11-2015	01:00:00	01-11-2015	14:30:00	84	Initial problem (engine not starting)	13.5	DS5
BD6	34	03-11-2015	14:59:00	04-11-2015	13:30:00	48.48	Hydraulic oil leakage	22.52	DS6
BD6	35	20-11-2015	13:00:00	20-11-2015	15:04:05	383.5	Initial problem (engine not starting)	2.07	DS5
BD6	36	24-11-2015	09:45:00	25-11-2015	13:30:00	90.68	Electrical breakdown	27.75	DS4
BD6	37	28-11-2015	07:00:00	28-11-2015	13:40:00	65.5	Initial problem (engine not starting)	6.67	DS5
BD6	38	04-12-2015	15:30:00	05-12-2015	14:00:56	145.83	Hydraulic oil leakage	22.52	DS6
BD6	39	26-12-2015	12:00:00	26-12-2015	13:49:50	501.98	Transmission, convertor gears not upshift	1.83	DS10
BD6	40	30-12-2015	07:30:00	31-12-2015	10:32:53	89.67	Initial problem (engine not starting)	27.05	DS5
BD6	41	04-01-2016	01:00:00	04-01-2016	10:00:00	86.45	Tyre punctured	9	DS2
BD6	42	13-01-2016	14:52:43	14-01-2016	14:34:06	220.88	Gears not engaging	23.69	DS4
BD6	43	17-01-2016	14:27:14	18-01-2016	14:00:00	71.89	Hydraulic oil leakage	23.55	DS5

BD6	44	20-01-2016	08:00:00	20-01-2016	14:00:00	42	Initial problem (engine not starting)	6	DS5
BD6	45	30-01-2016	09:30:00	30-01-2016	11:45:00	235.5	Initial problem (engine not starting)	2.25	DS4
					MTBF of BD6	**139.9**	**MTTR of BD6**	**18.55**	
Systems	**No. of failures**	**Start Date**	**Start Time**	**End date**	**End Time**	**TBF, hrs**	**Reasons**	**TTR, hrs**	**Failure Codes**
KD7	1	02-04-2017	06:02:08	04-04-2017	14:45:00	0	Head lights problem	56.71	DS4
KD7	2	06-04-2017	13:30:00	06-04-2017	17:50:00	46.75	Bucket hoisting problem	4.33	DS6
KD7	3	06-04-2017	19:30:00	11-04-2017	21:00:06	1.67	Bucket hoisting problem	121.5	DS6
KD7	4	12-04-2017	19:05:00	12-04-2017	21:15:00	22.08	Head lights problem	2.17	DS4
KD7	5	13-04-2017	20:30:00	14-04-2017	11:00:00	23.25	Head lights problem	14.5	DS4
KD7	6	14-04-2017	14:45:00	14-04-2017	23:34:28	3.75	Head lights problem	8.82	DS4
KD7	7	16-04-2017	18:45:30	18-04-2017	14:50:00	43.18	Transmission, convertor transmission oil	44.08	DS10
KD7	8	25-04-2017	23:30:00	26-04-2017	00:30:00	176.67	Reverse light not glowing	1	DS4
KD7	9	28-04-2017	02:00:00	28-04-2017	04:10:00	49.5	Parking brake not functioning properly	2.17	DS1
KD7	10	28-04-2017	07:30:00	28-04-2017	09:00:00	3.33	Problem occurred in operator	1.5	DS8
KD7	11	02-05-2017	12:30:00	03-05-2017	13:25:00	99.5	Hydraulic oil leakage	24.92	DS6
KD7	12	03-05-2017	14:00:00	03-05-2017	16:10:00	0.58	Hoist problem	2.17	DS5
KD7	13	05-05-2017	07:30:00	13-05-2017	20:00:00	39.33	Exhaust gases leakage	204.5	DS5
KD7	14	14-05-2017	08:00:00	14-05-2017	08:20:00	12	Electrical breakdown	0.33	DS4
KD7	15	15-05-2017	07:30:00	15-05-2017	20:45:00	23.17	Tyre O-ring failed	13.25	DS9
KD7	16	01-06-2017	06:45:00	02-06-2017	19:00:35	394	Head lights problem	36.26	DS4
KD7	17	04-06-2017	23:30:00	04-06-2017	23:45:00	52.49	Lighting problem	0.25	DS4
KD7	18	06-06-2017	23:30:00	06-06-2017	23:55:00	47.75	Electrical breakdown	0.42	DS4
KD7	19	16-06-2017	07:30:00	16-06-2017	16:00:00	223.58	Transmission, convertor transmission oil	8.5	DS10
KD7	20	19-06-2017	15:30:00	20-06-2017	17:30:28	71.5	Tyre got damaged	26.01	DS9
KD7	21	21-06-2017	20:30:45	21-06-2017	21:25:25	27	Head lights problem	0.91	DS4
KD7	22	23-06-2017	18:15:50	24-06-2017	11:30:00	44.84	Hydraulic hose failed	17.24	DS5
KD7	23	03-07-2017	17:20:00	04-07-2017	07:00:00	221.83	Hydraulic hose failed	13.67	DS5
KD7	24	04-07-2017	07:30:01	05-07-2017	12:00:00	0.5	Hydraulic oil leakage	28.5	DS6
KD7	25	05-07-2017	18:10:00	06-07-2017	23:55:41	6.17	Transmission, convertor transmission oil	29.76	DS10
KD7	26	10-07-2017	19:35:30	10-07-2017	20:37:11	91.66	Reverse light not glowing	1.03	DS4
KD7	27	18-07-2017	07:00:57	18-07-2017	08:30:44	178.4	Tyre air inflation less	1.5	DS9

KD7	28	20-07-2017	10:00:00	20-07-2017	10:01:00	49.49	Foot step ladder damaged	0.02	DS8
KD7	29	21-07-2017	23:30:00	22-07-2017	00:20:00	37.48	Reverse light not glowing	0.83	DS4
KD7	30	22-07-2017	10:00:01	22-07-2017	23:50:00	9.67	Tyre got damaged	13.83	DS9
KD7	31	28-07-2017	21:12:17	28-07-2017	23:45:00	141.37	Bucket hoist problem	2.55	DS4
KD7	32	30-07-2017	11:30:00	30-07-2017	18:15:26	35.75	Electrical breakdown	6.76	DS4
KD7	33	31-07-2017	05:00:00	31-07-2017	17:00:59	10.74	Hydraulic oil leakage	12.02	DS6
KD7	34	04-08-2017	23:45:00	18-08-2017	12:00:00	102.73	Parking brake not functioning properly	324.25	DS1
KD7	35	20-08-2017	15:30:00	21-08-2017	16:00:00	51.5	Turbo lube oil supply hose leak	24.5	DS5
KD7	36	22-08-2017	13:00:00	22-08-2017	14:15:00	21	Rear view mirror broken	1.25	DS8
KD7	37	22-08-2017	15:30:48	22-08-2017	16:00:39	1.26	No side mirror	0.5	DS8
KD7	38	23-08-2017	07:40:00	23-08-2017	09:00:00	15.66	No cabin fan	1.33	DS8
KD7	39	27-08-2017	23:30:00	27-08-2017	23:55:00	110.5	Reverse light not glowing	0.42	DS4
KD7	40	04-09-2017	07:00:00	04-09-2017	08:00:00	175.08	Boulder got jammed between rear tyres	1	DS2
KD7	41	05-09-2017	23:30:07	06-09-2017	01:50:05	39.5	Reverse light not glowing	2.33	DS4
KD7	42	07-09-2017	01:45:43	07-09-2017	23:55:00	23.93	Diesel leakage	22.15	DS5
KD7	43	10-09-2017	18:55:42	10-09-2017	19:30:20	67.01	Reverse light not glowing	0.58	DS4
KD7	44	12-09-2017	12:00:00	12-09-2017	19:00:00	40.49	Tyre puncture	7	DS9
KD7	45	13-09-2017	15:30:27	13-09-2017	23:45:00	20.51	Problem occurred in operator	8.24	DS8
KD7	46	14-09-2017	08:20:00	16-09-2017	23:50:00	8.58	Pivot pin excess play	63.5	DS2
KD7	47	18-09-2017	02:30:00	18-09-2017	03:30:00	26.67	Reverse light not glowing	1	DS4
KD7	48	18-09-2017	07:30:27	18-09-2017	08:45:41	4.01	Diesel leakage	1.25	DS5
KD7	49	19-09-2017	07:30:44	19-09-2017	08:00:25	22.75	Diesel leakage	0.49	DS5
KD7	50	21-09-2017	21:00:00	23-09-2017	13:20:44	60.99	Transmission, convertor transmission oil	16.35	DS10
KD7	51	05-10-2017	07:30:00	17-10-2017	09:50:00	282.15	Foot step ladder damaged	2.33	DS8
KD7	52	19-10-2017	05:00:00	19-10-2017	13:10:00	43.17	Diesel leakage	8.17	DS4
KD7	53	20-10-2017	23:40:00	22-10-2017	11:30:00	34.5	Diesel leakage	35.83	DS4
KD7	54	22-10-2017	17:40:00	22-10-2017	18:00:00	6.17	Cabin door glass problem	0.33	DS8
KD7	55	24-10-2017	07:01:00	24-10-2017	08:00:00	37.02	Tyre air inflation less	0.98	DS9
KD7	56	30-10-2017	11:30:00	31-10-2017	03:30:00	147.5	Cabin door glass problem	16	DS8
KD7	57	01-11-2017	07:00:43	07-11-2017	13:00:00	27.51	Hydraulic hose failed	149.99	DS5
KD7	58	07-11-2017	15:01:00	08-11-2017	00:10:10	2.02	Electrical breakdown	9.15	DS4
KD7	59	11-11-2017	14:30:13	11-11-2017	23:55:45	86.33	Bucket hoisting problem	9.43	DS10

KD7	60	14-11-2017	06:30:00	14-11-2017	16:00:00	54.57	Head lights problem	9.5	DS4
KD7	61	14-11-2017	16:20:00	15-11-2017	00:15:00	0.33	Steering hard	7.92	DS7
KD7	62	16-11-2017	06:30:00	16-11-2017	13:00:00	30.25	Lighting problem	6.5	DS4
KD7	63	21-11-2017	01:00:00	21-11-2017	10:20:41	108	Bucket hoist problem	9.34	DS4
KD7	64	21-11-2017	16:00:00	21-11-2017	18:15:00	5.66	Bucket hoisting problem	2.25	DS6
KD7	65	22-11-2017	11:30:00	23-11-2017	08:15:53	17.25	Engine rpm not raising/lowering	20.76	DS4
KD7	66	23-11-2017	21:45:00	24-11-2017	17:30:00	13.49	Rear view mirror broken	19.75	DS8
KD7	67	04-12-2017	23:30:00	05-12-2017	00:30:00	246	Lighting problem	1	DS4
KD7	68	08-12-2017	03:20:00	08-12-2017	17:14:41	74.83	Bucket hinge pin came out	13.91	DS2
KD7	69	11-12-2017	15:30:00	12-12-2017	00:05:30	70.26	Bucket hinge broken	8.59	DS8
KD7	70	12-12-2017	15:30:00	12-12-2017	20:00:00	15.41	Radius rod pin broken	4.5	DS8
KD7	71	15-12-2017	07:30:00	16-12-2017	18:00:00	59.5	Tyre puncture	34.5	DS9
KD7	72	17-12-2017	23:30:27	18-12-2017	00:15:19	29.51	Reverse light not glowing	0.75	DS4
KD7	73	19-12-2017	16:00:00	20-12-2017	23:45:21	39.74	Alternator belt cut/ missed	31.76	DS4
KD7	74	21-12-2017	10:30:00	21-12-2017	23:55:00	10.74	No water in radiator	13.42	DS4
KD7	75	22-12-2017	11:25:18	22-12-2017	14:00:00	11.51	Head lights problem	2.58	DS4
KD7	76	23-12-2017	23:30:09	24-12-2017	00:01:55	33.5	Reverse light not glowing	0.53	DS4
KD7	77	25-12-2017	17:50:00	26-12-2017	01:50:00	41.8	Hydraulic oil leakage	8	DS6
KD7	78	27-12-2017	06:30:00	27-12-2017	12:00:00	28.67	Head lights problem	5.5	DS4
KD7	79	01-01-2018	00:30:00	01-01-2018	16:45:00	108.5	No water in radiator	16.25	DS4
KD7	80	02-01-2018	18:30:00	03-01-2018	18:50:00	25.75	Foot step ladder damaged	2.33	DS8
KD7	81	16-01-2018	00:05:46	31-01-2018	02:30:19	293.26	Diesel leakage	8.17	DS4
KD7	82	11-02-2018	07:30:00	11-02-2018	11:45:00	268.99	Diesel leakage	35.83	DS4
KD7	83	18-02-2018	06:15:56	05-03-2018	06:34:44	162.52	Cabin door glass problem	0.33	DS8
KD7	84	09-03-2018	12:01:00	08-03-2018	12:55:00	101.44	Tyre air inflation less	0.98	DS9
KD7	85	09-03-2018	14:40:00	10-03-2018	16:10:20	25.75	Cabin door glass problem	16	DS8
KD7	86	22-03-2018	05:50:00	23-04-2018	05:55:00	277.66	Hydraulic hose failed	149.99	DS5
KD7	87	25-04-2018	11:50:00	13-04-2018	12:15:00	53.92	Electrical breakdown	9.15	DS4
KD7	88	16-04-2018	12:01:00	18-04-2018	20:30:00	71.77	Bucket hoisting problem	9.43	DS10
MTBF of KD7						**67.37**	**MTTR of KD7**	**21.135**	

Systems	No. of failures	Start Date	Start Time	End date	End Time	TBF, hrs	Reasons	TTR, hrs	Failure Codes
KD8	1	02-04-2017	07:03:28	02-04-2017	09:00:00	0	Radiator leakage	1.94	DS5
KD8	2	02-04-2017	23:45:27	03-04-2017	09:00:00	14.76	Head lights problem	9.24	DS4
KD8	3	03-04-2017	18:30:00	03-04-2017	19:00:00	9.5	Initial problem (engine not starting)	0.5	DS5
KD8	4	04-04-2017	17:00:00	04-04-2017	19:45:00	22	Water leak from engine manifold	2.75	DS5
KD8	5	16-04-2017	10:30:00	16-04-2017	13:00:00	278.75	Problem occurred in operator chamber	2.5	DS8
KD8	6	16-04-2017	23:30:00	17-04-2017	14:15:00	10.5	Brake oil hose failed	14.75	DS1
KD8	7	18-04-2017	18:00:50	19-04-2017	00:10:00	27.76	Bucket hoisting problem	6.15	DS2
KD8	8	21-04-2017	17:15:59	23-04-2017	00:20:00	65.1	Tyre punctured	31.07	DS9
KD8	9	25-04-2017	18:00:00	25-04-2017	19:40:00	65.67	Hydraulic oil level low	1.67	DS6
KD8	10	26-04-2017	04:10:00	26-04-2017	14:00:00	8.5	Hydraulic hose failed	9.83	DS5
KD8	11	01-05-2017	08:00:00	01-05-2017	08:50:00	114	Air lock problem	0.83	DS5
KD8	12	01-05-2017	16:00:00	02-05-2017	03:45:15	7.17	A / c not working	11.75	DS8
KD8	13	03-05-2017	16:30:00	03-05-2017	23:30:52	36.75	Cabin vibration	7.01	DS8
KD8	14	05-05-2017	07:00:00	05-05-2017	08:30:00	31.49	Tyre air inflation less	1.5	DS9
KD8	15	05-05-2017	20:30:00	06-05-2017	12:00:00	12	Bucket hoisting problem	15.5	DS5
KD8	16	06-05-2017	18:30:00	06-05-2017	18:45:00	6.5	Electrical breakdown	0.25	DS4
KD8	17	08-05-2017	10:00:00	08-05-2017	11:00:00	39.25	A / c not working	1	DS8
KD8	18	09-05-2017	09:30:00	09-05-2017	15:15:00	22.5	Hydraulic oil leakage	5.75	DS6
KD8	19	17-05-2017	17:15:39	17-05-2017	17:45:08	194.01	Tyre got damaged	0.49	DS9
KD8	20	18-05-2017	02:40:00	20-05-2017	00:40:00	8.91	Hydraulic oil level low	46	DS6
KD8	21	22-05-2017	09:20:00	22-05-2017	16:30:00	56.67	Hydraulic oil leakage	7.17	DS6
KD8	22	24-05-2017	03:36:46	24-05-2017	08:20:00	35.11	Electrical breakdown	4.72	DS4
KD8	23	24-05-2017	18:30:00	25-05-2017	09:45:00	10.17	Hydraulic oil leakage	15.25	DS6
KD8	24	27-05-2017	11:30:00	27-05-2017	16:45:00	49.75	Gears not engaging	5.25	DS4
KD8	25	27-05-2017	16:50:00	27-05-2017	18:40:00	0.08	Hydraulic oil level low	1.83	DS6
KD8	26	02-06-2017	04:10:00	03-06-2017	00:15:00	129.5	Alternator belt cut/ missed	20.08	DS4
KD8	27	07-06-2017	10:50:00	07-06-2017	15:35:00	106.58	Hydraulic oil leakage	4.75	DS6
KD8	28	13-06-2017	17:45:00	13-06-2017	23:45:17	146.17	Hydraulic oil level low	6	DS6
KD8	29	16-06-2017	20:30:00	16-06-2017	20:50:00	68.75	Lighting problem	0.33	DS4
KD8	30	18-06-2017	10:10:00	19-06-2017	22:27:27	37.33	Electrical breakdown	36.29	DS4

KD8	31	21-06-2017	13:00:00	21-06-2017	23:45:00	38.54	Hydraulic oil leakage	10.75	DS6
KD8	32	29-06-2017	15:30:00	29-06-2017	17:45:00	183.75	A / c not working	2.25	DS8
KD8	33	04-07-2017	21:40:00	05-07-2017	16:30:00	123.92	Failure occurred in suspension system	18.83	DS6
KD8	34	07-07-2017	08:00:00	07-07-2017	14:55:00	39.5	Suspension oil leakage f/r	6.92	DS6
KD8	35	08-07-2017	16:30:00	08-07-2017	18:00:00	25.58	Bucket hoisting problem	1.5	DS5
KD8	36	11-07-2017	11:40:00	11-07-2017	16:20:50	65.67	Suspension oil leakage f/r	4.68	DS6
KD8	37	12-07-2017	09:30:00	12-07-2017	11:40:00	17.15	Failure occurred in suspension system	2.17	DS6
KD8	38	12-07-2017	13:30:00	12-07-2017	22:40:00	1.83	Failure occurred in suspension system	9.17	DS6
KD8	39	14-07-2017	06:05:00	14-07-2017	15:01:00	31.42	Brake oil hose failed	8.93	DS1
KD8	40	15-07-2017	05:30:00	15-07-2017	16:00:16	14.48	Brake oil hose failed	10.5	DS1
KD8	41	16-07-2017	13:15:57	16-07-2017	14:03:39	21.26	Suspension hammering	0.8	DS6
KD8	42	16-07-2017	16:15:00	16-07-2017	22:15:00	2.19	Suspension oil leakage f/l	6	DS6
KD8	43	17-07-2017	18:20:00	18-07-2017	00:30:00	20.08	Suspension oil leakage f/r	6.17	DS6
KD8	44	18-07-2017	07:00:46	18-07-2017	08:20:28	6.51	Tyre air inflation less	1.33	DS9
KD8	45	20-07-2017	19:15:00	20-07-2017	23:30:00	58.91	Gears not engaging	4.25	DS4
KD8	46	20-07-2017	23:50:00	21-07-2017	12:30:55	0.33	Transmission, convertor gears not engaging	12.68	DS10
KD8	47	21-07-2017	15:30:00	21-07-2017	19:30:00	2.98	Cabin door glass problem	4	DS8
KD8	48	21-07-2017	23:30:00	22-07-2017	00:15:00	4	Reverse light not glowing	0.75	DS4
KD8	49	23-07-2017	09:00:00	23-07-2017	10:20:00	32.75	Suspension hammering	1.33	DS6
KD8	50	23-07-2017	20:40:00	23-07-2017	23:30:00	10.33	Failure occurred in suspension system	2.83	DS6
KD8	51	25-07-2017	18:15:00	25-07-2017	22:50:00	42.75	Failure occurred in suspension system	4.58	DS6
KD8	52	26-07-2017	10:00:00	26-07-2017	17:30:00	11.17	Suspension hammering	7.5	DS6
KD8	53	27-07-2017	08:30:00	27-07-2017	16:20:00	15	Suspension hammering	7.83	DS6
KD8	54	28-07-2017	07:30:00	28-07-2017	09:00:00	15.17	No water in radiator	1.5	DS5
KD8	55	29-07-2017	09:45:00	29-07-2017	16:10:00	24.75	Hydraulic oil level low	6.42	DS6
KD8	56	30-07-2017	02:26:24	31-07-2017	13:30:00	10.27	Electrical breakdown	35.06	DS4
KD8	57	01-08-2017	02:05:00	01-08-2017	02:30:00	12.58	Lighting problem	0.42	DS4
KD8	58	02-08-2017	06:10:00	02-08-2017	14:59:00	27.67	Suspension hammering	8.82	DS6
KD8	59	04-08-2017	09:30:00	05-08-2017	15:00:00	42.52	Hydraulic hose failed	29.5	DS6
KD8	60	06-08-2017	10:50:34	06-08-2017	15:15:27	19.84	Electrical breakdown	4.41	DS4
KD8	61	07-08-2017	03:30:00	07-08-2017	04:30:00	12.24	Initial problem (engine not starting)	1	DS4
KD8	62	09-08-2017	18:00:00	10-08-2017	12:00:00	61.5	Suspension oil leakage f/r	18	DS6

KD8	63	10-08-2017	23:30:00	11-08-2017	00:20:00	11.5	Electrical breakdown	0.83	DS4
KD8	64	11-08-2017	18:30:00	12-08-2017	00:15:00	18.17	Suspension hammering	5.75	DS6
KD8	65	17-08-2017	03:30:37	17-08-2017	04:30:33	123.26	Cabin door glass problem	1	DS8
KD8	66	17-08-2017	23:30:21	19-08-2017	14:25:00	19	Transmission, convertor gears not engaging	38.91	DS10
KD8	67	20-08-2017	18:00:00	20-08-2017	19:00:00	27.58	Rock ejector missing	1	DS2
KD8	68	20-08-2017	23:30:00	21-08-2017	00:30:00	4.5	Lighting problem	1	DS4
KD8	69	21-08-2017	07:01:00	21-08-2017	09:30:00	6.52	Tyre air inflation less	2.48	DS9
KD8	70	21-08-2017	10:30:00	21-08-2017	11:50:00	1	Abnormal sound from engine	1.33	DS5
KD8	71	21-08-2017	17:00:00	22-08-2017	00:05:00	5.17	Suspension oil leakage f/l	7.08	DS6
KD8	72	22-08-2017	11:30:00	22-08-2017	16:40:37	11.42	Cabin mounting bolts missing	5.18	DS8
KD8	73	22-08-2017	18:45:51	24-08-2017	17:00:24	2.09	Electrical breakdown	46.24	DS4
KD8	74	25-08-2017	07:01:00	25-08-2017	08:20:00	14.01	Tyre air inflation less	1.32	DS9
KD8	75	25-08-2017	15:58:51	25-08-2017	16:05:49	7.65	No water in radiator	0.12	DS5
KD8	76	26-08-2017	09:30:00	26-08-2017	09:50:00	17.4	Head lights problem	0.33	DS4
KD8	77	29-08-2017	07:30:00	29-08-2017	09:30:00	69.67	Transmission guard problem	2	DS10
KD8	78	06-09-2017	10:00:00	06-09-2017	15:00:00	192.5	Cabin door glass problem	5	DS8
KD8	79	22-09-2017	15:01:00	22-09-2017	17:00:00	384.02	Cabin door lock problem	1.98	DS8
KD8	80	23-09-2017	16:00:00	23-09-2017	17:30:00	23	Foot step ladder damaged	1.5	DS8
KD8	81	27-09-2017	17:20:00	27-09-2017	17:30:00	95.83	Reverse light not glowing	0.17	DS4
KD8	82	29-09-2017	04:40:42	29-09-2017	14:40:00	35.18	Rock ejector got bend	9.99	DS2
KD8	83	30-09-2017	05:00:00	01-10-2017	16:30:15	14.33	Brake oil hose failed	35.5	DS1
KD8	84	02-10-2017	01:00:00	02-10-2017	13:45:00	8.5	Water boiling	12.75	DS5
KD8	85	03-10-2017	06:30:00	03-10-2017	09:00:00	16.75	Lighting problem	2.5	DS4
KD8	86	04-10-2017	23:30:00	07-10-2017	00:10:00	38.5	No water in radiator	48.67	DS5
KD8	87	07-10-2017	08:25:00	07-10-2017	09:40:00	8.25	Electrical breakdown	1.25	DS4
KD8	88	08-10-2017	07:30:00	08-10-2017	08:30:00	21.83	Boulder got jammed between rear tyres	1	DS2
KD8	89	09-10-2017	07:30:01	09-10-2017	08:30:35	23	Tyre air inflation less	1.01	DS9
KD8	90	10-10-2017	12:00:00	10-10-2017	16:30:00	27.49	Brake oil hose failed	4.5	DS1
KD8	91	11-10-2017	07:30:00	11-10-2017	11:30:00	15	Tyre O-ring failed	4	DS9
KD8	92	14-10-2017	08:05:37	14-10-2017	11:00:05	68.59	Cabin door lock problem	2.91	DS8
KD8	93	16-10-2017	06:45:01	16-10-2017	16:20:00	43.75	Radiator leakage	9.58	DS8
KD8	94	20-10-2017	23:55:00	21-10-2017	10:30:00	103.58	Cabin door lock problem	10.58	DS8

KD8	95	24-10-2017	07:01:00	24-10-2017	08:10:00	68.52	Tyre air inflation less	1.15	DS9
KD8	96	25-10-2017	07:01:00	25-10-2017	08:20:00	22.85	Tyre air inflation less	1.32	DS9
KD8	97	27-10-2017	14:01:00	27-10-2017	18:30:39	53.68	Bucket hoisting problem	4.49	DS6
KD8	98	28-10-2017	07:30:00	28-10-2017	08:00:00	12.99	Cabin door lock problem	0.5	DS8
KD8	99	28-10-2017	22:30:00	29-10-2017	15:00:00	14.5	Tyre O-ring failed	16.5	DS9
KD8	100	01-11-2017	14:50:22	01-11-2017	18:20:00	71.84	Brake oil hose failed	3.49	DS1
KD8	101	02-11-2017	03:30:00	02-11-2017	04:30:00	9.17	Electrical breakdown	1	DS4
KD8	102	05-11-2017	16:00:00	05-11-2017	19:00:00	83.5	Hydraulic oil leakage	3	DS6
KD8	103	10-11-2017	20:30:00	10-11-2017	21:00:00	121.5	Electrical breakdown	0.5	DS4
KD8	104	15-11-2017	08:50:00	15-11-2017	14:00:00	107.83	Electrical breakdown	5.17	DS4
KD8	105	20-11-2017	05:40:00	20-11-2017	06:00:00	111.67	Electrical breakdown	0.33	DS4
KD8	106	22-11-2017	19:00:00	22-11-2017	22:30:00	61	Bucket hoisting problem	3.5	DS6
KD8	107	23-11-2017	08:45:48	23-11-2017	16:30:00	10.26	Electrical breakdown	7.74	DS4
KD8	108	23-11-2017	23:30:00	24-11-2017	00:30:00	7	Initial problem (engine not starting)	1	DS4
KD8	109	25-11-2017	01:50:00	25-11-2017	02:25:00	25.33	Initial problem (engine not starting)	0.58	DS4
KD8	110	26-11-2017	16:00:00	26-11-2017	16:30:00	37.58	Electrical breakdown	0.5	DS4
KD8	111	26-11-2017	18:50:00	26-11-2017	22:30:00	2.33	Electrical breakdown	3.67	DS4
KD8	112	27-11-2017	20:30:00	27-11-2017	21:00:00	22	Reverse light not glowing	0.5	DS4
KD8	113	28-11-2017	23:30:02	29-11-2017	11:30:00	26.5	Battery problem	12	DS4
KD8	114	29-11-2017	12:15:00	29-11-2017	16:50:00	0.75	Hydraulic oil leakage	4.58	DS6
KD8	115	30-11-2017	01:50:27	30-11-2017	08:30:00	9.01	Electrical breakdown	6.66	DS4
KD8	116	01-12-2017	13:20:00	01-12-2017	22:00:00	28.83	Hydraulic hose failed	8.67	DS5
KD8	117	03-12-2017	13:30:00	03-12-2017	15:45:19	39.5	Electrical breakdown	2.26	DS4
KD8	118	04-12-2017	15:30:10	04-12-2017	20:50:50	23.75	Electrical breakdown	5.34	DS4
KD8	119	05-12-2017	11:45:00	05-12-2017	17:00:57	14.9	Electrical breakdown	5.27	DS4
KD8	120	05-12-2017	18:30:31	05-12-2017	23:55:00	1.49	Reverse gear not engaging	5.41	DS4
KD8	121	08-12-2017	15:00:00	08-12-2017	16:00:00	63.08	A / c not working	1	DS8
KD8	122	09-12-2017	17:00:00	09-12-2017	22:30:00	25	Hydraulic hose failed	5.5	DS5
KD8	123	11-12-2017	04:00:00	11-12-2017	09:10:00	29.5	Electrical breakdown	5.17	DS4
KD8	124	12-12-2017	07:30:00	12-12-2017	16:15:00	22.33	Wheel bolts loose	8.75	DS9
KD8	125	13-12-2017	07:30:00	13-12-2017	09:00:00	15.25	Cabin door glass problem	1.5	DS8
KD8	126	15-12-2017	07:30:18	15-12-2017	20:00:00	46.51	Electrical breakdown	12.49	DS4

KD8	127	19-12-2017	06:00:00	19-12-2017	06:45:00	82	Electrical breakdown	0.75	DS4
KD8	128	19-12-2017	18:30:00	20-12-2017	23:45:12	11.75	Hydraulic oil level low	29.25	DS6
KD8	129	23-12-2017	04:25:15	23-12-2017	05:10:19	52.67	Electrical breakdown	0.75	DS4
KD8	130	27-12-2017	19:00:31	30-12-2017	19:30:03	109.84	Bucket hoisting problem	0.49	DS8
KD8	131	03-01-2018	21:00:00	21-01-2018	23:30:00	97.5	Initial problem (engine not starting)	4	DS4
KD8	132	30-01-2018	14:00:00	30-01-2018	01:50:00	206.5	Engine coolant leaking	13.06	DS5
KD8	133	01-02-2018	08:33:35	03-02-2018	11:40:08	54.73	Diesel leakage	3.39	DS5
KD8	134	20-02-2018	12:30:00	20-02-2018	13:30:00	408.83	Initial problem (engine not starting)	2	DS4
KD8	135	26-02-2018	14:53:53	27-02-2018	13:00:59	145.4	Exhaust smoke is black	5.74	DS5
KD8	136	11-03-2018	10:00:00	15-03-2018	14:27:02	284.98	Abnormal sound from engine	7.54	DS5
KD8	137	21-03-2018	06:15:00	22-03-2018	10:00:20	135.8	Engine rpm become slow	8.25	DS5
KD8	138	28-03-2018	14:49:32	28-03-2018	11:36:23	148.82	Engine rpm not raising/lowering	14.49	DS5
KD8	139	12-04-2018	15:10:00	25-04-2018	13:52:47	363.56	Initial problem (engine not starting)	10.5	DS4
KD8	140	27-04-2018	10:00:00	27-04-2018	09:24:17	44.12	Cabin fan problem	0.25	DS4
KD8	141	30-04-2018	11:00:00	02-05-2018	13:00:00	73.6	Initial problem (engine not starting)	13.24	DS5
					MTBF of KD8	**53.056**	**MTTR of KD8**	**7.33**	
Systems	**No. of failures**	**Start Date**	**Start Time**	**End date**	**End Time**	**TBF, hrs**	**Reasons**	**TTR, hrs**	**Failure Codes**
KD9	1	19-04-2017	12:28:02	20-04-2017	14:00:00	0	A / c not working	25.53	DS6
KD9	2	23-04-2017	07:30:27	30-04-2017	16:10:00	65.51	Tyre air inflation less	8.66	DS9
KD9	3	01-05-2017	09:45:00	10-05-2017	12:45:00	17.58	Bucket hoisting problem	3	DS2
KD9	4	16-05-2017	07:00:29	16-05-2017	08:00:53	138.26	Tyre air inflation less	1.01	DS9
KD9	5	18-05-2017	10:10:40	18-05-2017	17:00:00	50.16	Electrical breakdown	6.82	DS4
KD9	6	21-05-2017	16:45:00	22-05-2017	11:20:00	71.75	Hose failure	18.58	DS5
KD9	7	23-05-2017	17:40:56	23-05-2017	17:47:30	30.35	No power in cabin	0.11	DS4
KD9	8	28-05-2017	02:00:00	28-05-2017	09:30:00	104.21	Tyre O-ring failed	7.5	DS9
KD9	9	28-05-2017	11:16:21	29-05-2017	04:45:00	1.77	Fan belt failed	17.48	DS5
KD9	10	04-06-2017	07:30:00	04-06-2017	08:10:00	146.75	Tyre air inflation less	0.67	DS9
KD9	11	05-06-2017	18:15:00	05-06-2017	21:00:00	34.08	Brake oil hose failed	2.75	DS1
KD9	12	06-06-2017	17:50:00	07-06-2017	00:10:00	20.83	Brake oil hose failed	6.33	DS1
KD9	13	08-06-2017	16:00:00	18-06-2017	17:30:00	39.83	Alternator not working	1.5	DS4
KD9	14	24-06-2017	11:30:00	25-06-2017	14:28:00	138	Alternator belt cut/ missed	26.97	DS4

KD9	15	26-06-2017	12:00:00	26-06-2017	14:45:00	21.53	Water leak from radiator hose / pipe	2.75	DS5
KD9	16	26-06-2017	17:30:00	27-06-2017	00:30:00	2.75	Water temperature raising	7	DS5
KD9	17	28-06-2017	07:30:24	28-06-2017	12:30:43	31.01	No water in radiator	5.01	DS5
KD9	18	28-06-2017	18:30:00	29-06-2017	15:45:00	5.99	No water in radiator	21.25	DS5
KD9	19	29-06-2017	17:00:01	29-06-2017	21:50:00	1.25	Diesel leakage	4.83	DS5
KD9	20	04-07-2017	23:30:58	05-07-2017	00:05:00	121.68	Head lights problem	0.57	DS5
KD9	21	06-07-2017	16:00:00	06-07-2017	18:30:00	39.92	Hydraulic hose failed	2.5	DS6
KD9	22	07-07-2017	13:30:00	08-07-2017	23:30:00	19	Engine oil leakage	34	DS5
KD9	23	10-07-2017	10:30:00	10-07-2017	11:45:00	35	Ladder / railing damaged	1.25	DS8
KD9	24	12-07-2017	07:01:00	12-07-2017	18:00:00	43.27	Tyre punctured	10.98	DS9
KD9	25	12-07-2017	23:01:00	13-07-2017	15:01:00	5.02	Tyre punctured	16	DS9
KD9	26	15-07-2017	07:30:00	15-07-2017	07:31:00	40.48	Electrical breakdown	0.02	DS4
KD9	27	15-07-2017	13:01:00	16-07-2017	12:20:53	5.5	Electrical breakdown	23.33	DS4
KD9	28	19-07-2017	07:30:00	19-07-2017	08:30:00	67.15	Hose guard detached	1	DS5
KD9	29	20-07-2017	07:30:00	20-07-2017	08:10:00	23	Tyre air inflation less	0.67	DS9
KD9	30	20-07-2017	23:30:00	21-07-2017	00:40:00	15.33	Cabin fan not working	1.17	DS4
KD9	31	22-07-2017	07:00:00	22-07-2017	12:00:00	30.33	Tyre air inflation less	5	DS9
KD9	32	22-07-2017	13:00:01	22-07-2017	20:45:00	1	Tyre air inflation less	7.75	DS9
KD9	33	25-07-2017	10:15:00	25-07-2017	12:30:00	61.5	A / c not working	2.25	DS4
KD9	34	25-07-2017	23:30:35	26-07-2017	00:05:49	11.01	Engine oil leakage	0.59	DS5
KD9	35	01-08-2017	23:30:00	02-08-2017	12:00:00	167.4	A / c not working	12.5	DS4
KD9	36	03-08-2017	09:30:00	03-08-2017	16:00:24	21.5	Cabin vibration	6.51	DS8
KD9	37	03-08-2017	23:30:00	04-08-2017	00:10:00	7.49	Reverse light not glowing	0.67	DS4
KD9	38	04-08-2017	07:30:00	04-08-2017	08:00:00	7.33	Problem occurred in operator	0.5	DS8
KD9	39	13-08-2017	02:30:00	18-08-2017	15:00:00	210.5	Engine rpm become slow	132.5	DS5
KD9	40	18-08-2017	17:01:00	19-08-2017	01:00:00	2.02	Suspension weak f/l	7.98	DS6
KD9	41	21-08-2017	07:30:00	21-08-2017	16:00:00	54.5	A / c not working	8.5	DS4
KD9	42	22-08-2017	09:30:00	22-08-2017	16:00:12	17.5	Cabin vibration	6.5	DS8
KD9	43	23-08-2017	01:40:00	23-08-2017	11:40:00	9.66	A / c not working	10	DS4
KD9	44	24-08-2017	06:20:00	24-08-2017	14:50:00	18.67	Engine oil leakage	8.5	DS5
KD9	45	27-08-2017	11:30:00	27-08-2017	19:15:00	68.67	Tyre O-ring failed	7.75	DS9
KD9	46	31-08-2017	15:30:00	31-08-2017	19:50:00	92.25	Cabin door glass problem	4.33	DS8

KD9	47	02-09-2017	16:06:32	02-09-2017	23:35:00	44.28	Hoist problem	7.47	DS6
KD9	48	02-09-2017	23:40:00	03-09-2017	10:30:00	0.08	Fuse problem	10.83	DS4
KD9	49	03-09-2017	23:30:20	03-09-2017	23:50:18	13.01	Reverse light not glowing	0.33	DS4
KD9	50	04-09-2017	10:40:00	04-09-2017	17:00:00	10.83	Hydraulic oil leakage	6.33	DS6
KD9	51	11-09-2017	07:30:00	11-09-2017	20:40:00	158.5	Tyre got damaged	13.17	DS9
KD9	52	13-09-2017	17:45:39	13-09-2017	17:55:40	45.09	Horn problem	0.17	DS4
KD9	53	15-09-2017	18:00:00	15-09-2017	18:45:00	48.07	Steering hard	0.75	DS7
KD9	54	16-09-2017	23:30:00	17-09-2017	00:15:00	28.75	Lighting problem	0.75	DS4
KD9	55	25-09-2017	18:45:00	26-09-2017	11:15:00	210.5	Head lights problem	16.5	DS4
KD9	56	28-09-2017	10:30:00	28-09-2017	19:00:00	47.25	Electrical breakdown	8.5	DS4
KD9	57	29-09-2017	02:30:06	29-09-2017	23:50:00	7.5	Electrical breakdown	21.33	DS4
KD9	58	02-10-2017	06:30:00	02-10-2017	17:00:51	54.67	Exhaust gases leakage	10.51	DS5
KD9	59	04-10-2017	09:00:00	04-10-2017	09:45:00	39.99	A/C not working	0.75	DS4
KD9	60	04-10-2017	11:30:00	04-10-2017	16:00:00	1.75	A/C not working	4.5	DS4
KD9	61	04-10-2017	19:30:00	04-10-2017	22:13:00	3.5	Reverse light not glowing	2.72	DS4
KD9	62	05-10-2017	04:45:00	07-10-2017	00:10:00	6.53	Hydraulic hose failed	43.42	DS6
KD9	63	07-10-2017	10:30:00	07-10-2017	14:50:00	10.33	Hydraulic oil leakage	4.33	DS6
KD9	64	11-10-2017	01:45:00	11-10-2017	02:20:00	82.92	A/C not working	0.58	DS4
KD9	65	11-10-2017	07:30:00	11-10-2017	15:30:00	5.17	Oil leak from final drive	8	DS2
KD9	66	11-10-2017	20:30:00	11-10-2017	21:15:00	5	Lighting problem	0.75	DS4
KD9	67	16-10-2017	16:00:00	16-10-2017	16:30:00	114.75	A/C not working	0.5	DS4
KD9	68	17-10-2017	06:45:20	17-10-2017	12:45:00	14.26	Head lights problem	5.99	DS4
KD9	69	18-10-2017	06:45:53	18-10-2017	16:00:00	18.01	Brake oil hose failed	9.24	DS1
KD9	70	21-10-2017	08:40:00	23-10-2017	17:00:00	64.67	Radius rod holes worn out	56.33	DS8
KD9	71	23-10-2017	23:30:00	24-10-2017	00:05:00	6.5	Lighting problem	0.58	DS4
KD9	72	27-10-2017	07:30:00	27-10-2017	08:00:00	79.42	Cabin fan not working	0.5	DS4
KD9	73	28-10-2017	07:30:00	28-10-2017	08:00:00	23.5	Horn/buzzer not working	0.5	DS8
KD9	74	29-10-2017	08:35:04	29-10-2017	13:10:31	24.58	Horn/buzzer not working	4.59	DS8
KD9	75	02-11-2017	15:00:00	02-11-2017	19:15:00	97.82	Hydraulic oil level low	4.25	DS6
KD9	76	07-11-2017	07:30:00	07-11-2017	15:15:00	108.25	Tyre got damaged	7.75	DS9
KD9	77	08-11-2017	08:45:00	08-11-2017	12:00:00	17.5	A/C not working	3.25	DS4
KD9	78	10-11-2017	16:00:00	11-11-2017	00:20:09	52	Electrical breakdown	8.34	DS4

KD9	79	13-11-2017	15:30:32	13-11-2017	23:55:00	63.17	Problem occurred in grease injector	8.41	DS7
KD9	80	16-11-2017	18:25:33	17-11-2017	17:05:00	66.51	Hydraulic hose failed	22.66	DS6
KD9	81	19-11-2017	08:00:00	19-11-2017	08:10:00	38.92	Transmission, convertor transmission oil	0.17	DS10
KD9	82	23-11-2017	13:00:54	23-11-2017	16:30:00	100.85	Electrical breakdown	3.48	DS4
KD9	83	26-11-2017	10:15:00	26-11-2017	12:00:00	65.75	A/C not working	1.75	DS4
KD9	84	02-12-2017	03:45:46	02-12-2017	18:00:00	135.76	Hydraulic hose failed	14.24	DS6
KD9	85	02-12-2017	18:10:00	03-12-2017	09:00:00	0.17	Electrical breakdown	14.83	DS4
KD9	86	07-12-2017	07:01:00	07-12-2017	11:30:00	94.02	Tyre disc bend	4.48	DS9
KD9	87	07-12-2017	15:30:52	07-12-2017	16:35:40	4.01	Head lights problem	1.08	DS4
KD9	88	07-12-2017	18:00:32	29-12-2017	18:15:02	1.41	Reverse light not glowing	0.24	DS4
KD9	89	02-01-2018	02:00:00	31-01-2018	07:00:00	79.75	Air not building up to support engine	0.44	DS1
KD9	90	06-02-2018	01:46:36	18-02-2018	09:00:00	138.78	Steering cylinder oil leakage	2.62	DS7
KD9	91	18-02-2018	18:30:00	19-02-2018	13:45:08	9.5	Air leakage	5	DS1
KD9	92	21-02-2018	05:00:00	21-02-2018	07:00:00	39.25	Radiator leakage	0.5	DS5
KD9	93	08-03-2018	18:00:00	10-03-2018	12:00:00	371	Air hose failed	15.5	DS1
KD9	94	18-03-2018	23:20:00	27-03-2018	12:00:00	203.33	Air hose failed	44.05	DS1
KD9	95	22-04-2018	10:00:00	22-04-2018	13:15:00	622	Exhaust smoke is black	4	DS5
KD9	96	23-04-2018	16:02:51	25-04-2018	16:00:00	26.8	Excess blow bye	324.69	DS5
KD9	97	28-04-2018	11:00:26	30-04-2018	13:30:00	67.01	Hydraulic oil leakage	25.5	DS6
					MTBF of KD9	**58.67**	**MTTR of KD9**	**12.76**	

Systems	**No. of failures**	**Start Date**	**Start Time**	**End date**	**End Time**	**TBF, hrs**	**Reasons**	**TTR, hrs**	**Failure Codes**
KD10	1	03-04-2017	13:00:52	03-04-2017	23:30:29	0	Hydraulic hose failed	10.49	DS5
KD10	2	06-04-2017	07:30:00	06-04-2017	08:45:00	55.99	Tyre air inflation less	1.25	DS9
KD10	3	08-04-2017	17:30:00	08-04-2017	19:00:00	56.75	Bucket not lowering	1.5	DS6
KD10	4	10-04-2017	02:30:38	10-04-2017	10:30:00	31.51	Engine coolant leaking	7.99	DS5
KD10	5	10-04-2017	13:40:00	10-04-2017	23:30:26	3.17	Electrical breakdown	9.84	DS4
KD10	6	12-04-2017	07:30:00	12-04-2017	12:00:00	31.99	No water in radiator	4.5	DS5
KD10	7	12-04-2017	18:20:00	13-04-2017	12:45:00	6.33	Initial problem (engine not starting)	18.42	DS5
KD10	8	14-04-2017	07:30:00	14-04-2017	11:50:00	18.75	Water leak from radiator hose / pipe	4.33	DS5
KD10	9	14-04-2017	17:10:00	14-04-2017	22:35:00	5.33	Cabin vibration	5.42	DS8
KD10	10	15-04-2017	08:30:00	15-04-2017	13:00:00	9.92	Engine coolant leaking	4.5	DS5

KD10	11	15-04-2017	18:20:00	15-04-2017	19:00:00	5.33	No water in radiator	0.67	DS5
KD10	12	18-04-2017	09:00:00	18-04-2017	10:20:00	62	Initial problem (engine not starting)	1.33	DS5
KD10	13	18-04-2017	12:50:00	18-04-2017	16:00:45	2.5	Initial problem (engine not starting)	3.18	DS5
KD10	14	19-04-2017	09:20:00	19-04-2017	14:45:00	17.32	Initial problem (engine not starting)	5.42	DS5
KD10	15	21-04-2017	10:50:00	21-04-2017	14:50:00	44.08	Hose guard detached	4	DS5
KD10	16	21-04-2017	23:30:00	22-04-2017	14:30:00	8.67	A / c not working	15	DS4
KD10	17	24-04-2017	11:34:21	24-04-2017	22:10:00	45.07	Steering cylinder hose failure	10.59	DS7
KD10	18	25-04-2017	12:15:14	25-04-2017	15:30:00	14.09	Engine coolant leaking	3.25	DS5
KD10	19	25-04-2017	15:45:00	26-04-2017	22:30:00	0.25	Radiator leakage	30.75	DS5
KD10	20	26-04-2017	23:01:00	30-04-2017	11:00:00	0.52	No water in radiator	83.98	DS5
KD10	21	01-05-2017	01:35:12	01-05-2017	14:15:00	14.59	Initial problem (engine not starting)	12.66	DS5
KD10	22	01-05-2017	16:00:00	01-05-2017	23:40:28	1.75	A / c not working	7.67	DS4
KD10	23	02-05-2017	07:00:00	02-05-2017	07:45:00	7.33	Engine oil temperature raising	0.75	DS5
KD10	24	02-05-2017	09:30:00	02-05-2017	12:30:00	1.75	A / c not working	3	DS4
KD10	25	02-05-2017	18:15:00	02-05-2017	23:30:20	5.75	Water temperature raising	5.26	DS4
KD10	26	03-05-2017	07:01:00	03-05-2017	13:50:00	7.51	Gears not engaging	6.82	DS10
KD10	27	03-05-2017	16:30:00	03-05-2017	23:30:44	2.67	Water temperature raising	7.01	DS5
KD10	28	03-05-2017	23:45:45	04-05-2017	11:30:00	0.25	Initial problem (engine not starting)	11.74	DS5
KD10	29	05-05-2017	10:20:00	05-05-2017	17:30:00	22.83	Initial problem (engine not starting)	7.17	DS5
KD10	30	08-05-2017	12:15:00	08-05-2017	12:35:00	66.75	Electrical breakdown	0.33	DS4
KD10	31	08-05-2017	23:00:00	09-05-2017	15:01:00	10.42	Gears not engaging	16.02	DS4
KD10	32	10-05-2017	19:30:39	11-05-2017	08:45:00	28.49	Electrical breakdown	13.24	DS4
KD10	33	13-05-2017	16:00:00	13-05-2017	17:00:00	55.25	Bucket hoisting problem	1	DS6
KD10	34	13-05-2017	21:30:00	14-05-2017	00:30:00	4.5	Hoist problem	3	DS6
KD10	35	15-05-2017	09:50:00	17-05-2017	00:05:00	33.33	Grease container empty	38.25	DS2
KD10	36	17-05-2017	02:40:00	17-05-2017	05:30:00	2.58	Head lights problem	2.83	DS4
KD10	37	17-05-2017	06:30:00	17-05-2017	18:45:53	1	Head lights problem	12.26	DS4
KD10	38	17-05-2017	19:25:43	17-05-2017	22:40:35	0.66	Head lights problem	3.25	DS4
KD10	39	17-05-2017	23:30:00	18-05-2017	09:00:19	0.82	Head lights problem	9.51	DS4
KD10	40	18-05-2017	20:00:00	18-05-2017	21:30:00	10.99	Head lights problem	1.5	DS4
KD10	41	19-05-2017	18:40:00	19-05-2017	19:10:00	21.17	Water temperature raising	0.5	DS5
KD10	42	21-05-2017	04:15:00	21-05-2017	11:30:00	33.08	Bucket hoisting problem	7.25	DS6

KD10	43	26-05-2017	05:00:00	27-05-2017	12:00:00	113.5	Hydraulic oil leakage	31	DS6
KD10	44	02-06-2017	11:10:00	02-06-2017	17:00:49	143.17	Bucket hoisting problem	5.85	DS6
KD10	45	08-06-2017	23:30:00	09-06-2017	01:00:00	150.49	Lighting problem	1.5	DS4
KD10	46	10-06-2017	19:45:00	11-06-2017	08:30:00	42.75	Foot step ladder damaged	12.75	DS8
KD10	47	13-06-2017	12:15:00	13-06-2017	18:30:00	51.75	Steering struck up	6.25	DS7
KD10	48	17-06-2017	07:30:00	17-06-2017	08:15:00	85	No water in radiator	0.75	DS5
KD10	49	21-06-2017	07:30:00	21-06-2017	14:00:00	95.25	Ladder / railing damaged	6.5	DS8
KD10	50	22-06-2017	07:30:00	22-06-2017	08:00:00	17.5	Tyre O-ring failed	0.5	DS9
KD10	51	29-06-2017	15:30:00	29-06-2017	18:00:00	175.5	A/C not working	2.5	DS4
KD10	52	10-07-2017	10:30:00	10-07-2017	14:30:00	256.5	Hydraulic hose failed	4	DS5
KD10	53	12-07-2017	07:30:00	12-07-2017	14:00:00	41	Transmission, convertor transmission oil	6.5	DS10
KD10	54	21-07-2017	07:30:41	21-07-2017	08:00:46	209.51	Hydraulic oil leakage	0.5	DS6
KD10	55	23-07-2017	13:30:00	23-07-2017	18:30:00	53.49	Hydraulic oil leakage	5	DS6
KD10	56	24-07-2017	07:30:00	29-07-2017	16:10:00	13	Hydraulic oil leakage	128.67	DS6
KD10	57	30-07-2017	23:30:00	31-07-2017	00:05:00	31.33	Lighting problem	0.58	DS4
KD10	58	09-08-2017	15:30:00	09-08-2017	17:30:00	231.42	A/C not working	2	DS4
KD10	59	16-08-2017	07:30:00	16-08-2017	09:45:00	158	Radiator leakage	2.25	DS5
KD10	60	16-08-2017	13:10:00	16-08-2017	19:30:00	3.42	Brake oil hose failed	6.33	DS5
KD10	61	22-08-2017	17:00:57	23-08-2017	11:40:00	141.52	Transmission, convertor gears not engaging	18.65	DS10
KD10	62	23-08-2017	19:15:54	24-08-2017	14:50:00	7.6	Electrical breakdown	19.57	DS4
KD10	63	24-08-2017	16:30:25	24-08-2017	17:55:15	1.67	Electrical breakdown	1.41	DS4
KD10	64	25-08-2017	11:30:00	25-08-2017	13:00:00	17.58	Initial problem (engine not starting)	1.5	DS5
KD10	65	25-08-2017	16:00:31	26-08-2017	11:23:00	3.01	Suspension weak f/l	19.37	DS6
KD10	66	29-08-2017	19:10:00	29-08-2017	19:30:00	79.78	Head lights problem	0.33	DS4
KD10	67	01-09-2017	00:50:00	01-09-2017	18:00:00	53.33	Transmission not working	17.17	DS10
KD10	68	06-09-2017	02:50:41	06-09-2017	03:00:56	104.84	Electrical breakdown	0.17	DS4
KD10	69	14-09-2017	17:40:26	11-10-2017	17:00:00	206.66	Electrical breakdown	29	DS4
KD10	70	14-10-2017	02:20:00	25-10-2017	15:00:00	57.33	Hydraulic oil leakage	38.4	DS6
KD10	71	25-10-2017	15:03:00	03-11-2017	15:00:00	0.05	Oil leak from final drive	115.95	DS2
KD10	72	03-11-2017	15:02:00	08-12-2017	15:00:00	0.03	Oil leak from final drive	439.48	DS2
KD10	73	08-12-2017	15:01:00	17-12-2017	12:30:00	0.02	Oil leak from final drive	113.67	DS2
KD10	74	17-12-2017	16:00:00	17-12-2017	16:40:00	3.5	Rear view mirror broken	0.67	DS8

KD10	75	17-12-2017	23:30:56	18-12-2017	00:15:04	6.85	Reverse light not glowing	0.74	DS4
KD10	76	18-12-2017	10:15:00	18-12-2017	16:15:00	10	Rock ejector got bend	6	DS2
KD10	77	19-12-2017	01:00:00	19-12-2017	04:50:00	8.75	Electrical breakdown	3.83	DS4
KD10	78	20-12-2017	13:15:00	21-12-2017	11:00:00	32.42	Electrical breakdown	21.75	DS4
KD10	79	22-12-2017	09:00:00	22-12-2017	12:45:00	22	Electrical breakdown	3.75	DS4
KD10	80	22-12-2017	13:40:00	22-12-2017	16:30:00	0.92	Electrical breakdown	2.83	DS4
KD10	81	22-12-2017	17:40:00	23-12-2017	16:00:00	1.17	Electrical breakdown	22.33	DS4
KD10	82	23-12-2017	16:30:00	24-12-2017	11:40:00	0.5	Electrical breakdown	19.17	DS4
KD10	83	24-12-2017	14:00:00	24-12-2017	16:00:00	2.33	Electrical breakdown	2	DS4
KD10	84	27-12-2017	23:30:00	28-12-2017	08:40:00	79.5	Electrical breakdown	9.17	DS4
KD10	85	29-12-2017	23:30:00	30-12-2017	00:20:00	38.83	Head lights problem	0.83	DS4
KD10	86	01-01-2018	00:30:00	01-01-2018	16:45:00	48.17	No water in radiator	16.25	DS4
KD10	87	02-01-2018	18:30:00	03-01-2018	18:50:00	25.75	Foot step ladder damaged	2.33	DS8
KD10	88	16-01-2018	00:05:46	17-01-2018	02:30:19	293.26	Diesel leakage	8.17	DS5
KD10	89	11-02-2018	07:30:00	11-02-2018	11:45:00	604.99	Diesel leakage	35.83	DS5
KD10	90	18-02-2018	06:15:56	18-02-2018	06:34:44	162.52	Cabin door glass problem	0.33	DS8
KD10	91	08-03-2018	12:01:00	10-03-2018	12:55:00	437.44	Tyre air inflation less	0.98	DS2
KD10	92	10-03-2018	14:40:00	10-03-2018	16:10:20	1.75	Cabin door glass problem	16	DS8
KD10	93	22-03-2018	05:50:00	23-03-2018	05:55:00	277.66	Hydraulic hose failed	149.99	DS5
KD10	94	13-04-2018	11:50:00	13-04-2018	12:15:00	509.92	Electrical breakdown	9.15	DS4
KD10	95	16-04-2018	12:01:00	18-04-2018	20:30:00	71.77	Bucket hoisting problem	9.43	DS2
					MTBF of KD10	**62.52**	**MTTR of KD10**	18.706	

Table A.2 Failure and repair data of various subsystems of shovel and dumper in surface iron ore mine

Systems	No. of failures	Start Date	Start Time	End date	End Time	TBF, hrs	Reasons	TTR, hrs	Failure Codes
KS11	1	02-04-2017	09:08:34	02-04-2017	09:10:00	0.00	Grease hose failed	0.02	SS3
KS11	2	07-04-2017	10:25:29	07-04-2017	10:30:00	121.26	Hydraulic oil leakage	0.08	SS7
KS11	3	09-04-2017	08:00:00	09-04-2017	12:30:00	45.50	Track loose	4.50	SS10
KS11	4	06-05-2017	10:00:00	06-05-2017	11:00:00	645.50	Track not cutting	1.00	SS10
KS11	5	25-05-2017	00:00:43	25-05-2017	10:30:00	445.01	Radiator fan damaged	10.49	SS6
KS11	6	05-06-2017	16:00:00	05-06-2017	18:00:00	269.50	Track loose	2.00	SS10
KS11	7	07-06-2017	00:30:00	07-06-2017	01:15:00	30.50	Head lights problem	0.75	SS5
KS11	8	10-6-2017	08:30:48	11-06-2017	20:30:00	79.26	Tract failure in transmission	35.99	SS10
KS11	9	02-07-2017	07:00:00	04-07-2017	22:50:00	490.50	Track loose	63.83	SS10
KS11	10	24-07-2017	12:15:00	24-07-2017	15:15:00	469.42	Bucket hinge pin came out	3.00	SS3
KS11	11	04-08-2017	10:00:00	04-08-2017	11:30:00	258.75	Bucket hinge pin came out	1.50	SS3
KS11	12	05-08-2017	18:00:37	06-08-2017	08:30:39	30.51	Bucket hinge pin came out	14.50	SS3
KS11	13	08-08-2017	13:00:00	09-08-2017	00:30:00	52.49	Bucket changing work	11.50	SS3
KS11	14	09-08-2017	17:15:00	10-08-2017	13:00:00	16.75	Hydraulic oil leakage	19.75	SS7
KS11	15	13-08-2017	01:00:00	13-08-2017	01:10:00	60.00	Hydraulic oil leakage	0.17	SS7
KS11	16	13-08-2017	05:21:03	13-08-2017	05:23:00	4.18	Hydraulic oil leakage	0.03	SS7
KS11	17	21-08-2017	10:00:00	21-08-2017	14:00:00	196.62	Engine oil pressure low	4.00	SS6
KS11	18	22-08-2017	05:30:00	22-08-2017	08:45:00	15.50	Engine oil pressure low	3.25	SS6
KS11	19	11-09-2017	22:00:00	12-09-2017	00:45:00	493.25	Bucket hinge pin came out	2.75	SS3
KS11	20	16-09-2017	08:00:00	17-09-2017	13:27:00	103.25	Engine rpm become slow	29.45	SS6
KS11	21	20-09-2017	14:50:56	21-09-2017	11:09:05	73.40	Bucket hinge pin came out	20.30	SS3
KS11	22	22-09-2017	08:00:49	22-09-2017	14:59:47	20.86	Engine rpm become slow	6.98	SS6
KS11	23	23-09-2017	12:45:00	24-09-2017	14:00:00	21.75	Engine rpm become slow	25.25	SS6
KS11	24	25-09-2017	17:30:00	26-09-2017	14:30:00	27.50	Battery weak starting problem	21.00	SS5
KS11	25	23-10-2017	16:30:19	23-10-2017	17:00:26	650.01	Tooth point missed	0.50	SS3
KS11	26	24-10-2017	10:50:00	25-10-2017	07:01:00	17.83	Engine rpm not raising/lowering	20.18	SS6
KS11	27	25-10-2017	12:00:00	26-10-2017	17:00:01	4.98	Engine rpm not raising/lowering	29.00	SS6
KS11	28	27-10-2017	11:00:00	27-10-2017	14:30:00	18.00	Engine rpm not raising/lowering	3.50	SS6

KS11	29	02-12-2017	07:15:00	02-12-2017	09:00:00	856.75	Bucket hinge pin came out	1.75	SS3
KS11	30	13-12-2017	18:00:00	13-12-2017	22:30:00	273.00	Initial problem (engine not starting)	4.50	SS5
KS11	31	16-12-2017	17:45:00	16-12-2017	19:30:00	67.25	Track loose	1.75	SS10
					MTBF of KS11	**189.00**	**MTTR of KS11**	**11.07**	
Systems	**No. of failures**	**Start Date**	**Start Time**	**End date**	**End Time**	**TBF, hrs**	**Reasons**	**TTR, hrs**	**Failure Codes**
KS12	1	23-09-2017	16:00:00	23.09.2017	23:50:00	0.00	Hydraulic oil leakage	7.83	SS7
KS12	2	27-09-2017	15:01:00	27.09.2017	16:40:00	87.18	Hydraulic oil leakage	1.65	SS7
KS12	3	27-09-2017	18:45:00	27.09.2017	18:50:00	2.08	Water temperature raising	2.80	SS6
KS12	4	02-10-2017	15:30:28	02.10.2017	18:40:53	116.67	Hydraulic oil leakage	3.17	SS7
KS12	5	03-10-2017	13:30:00	03.10.2017	13:40:00	18.82	Electrical breakdown	0.17	SS5
KS12	6	15-10-2017	18:30:00	15.10.2017	19:00:00	292.83	Electrical breakdown	5.00	SS5
KS12	7	17-10-2017	03:45:12	17.10.2017	04:45:06	32.75	Initial problem (engine not starting)	1.00	SS5
KS12	8	17-10-2017	07:15:00	17.10.2017	08:30:00	2.50	Initial problem (engine not starting)	1.25	SS5
KS12	9	17-10-2017	19:20:00	17.10.2017	20:30:00	10.83	A/C not working	1.17	SS9
KS12	10	18-10-2017	06:30:00	18.10.2017	10:15:00	10.00	Hydraulic oil leakage	3.75	SS7
KS12	11	19-10-2017	10:20:00	19.10.2017	12:20:00	24.08	Water temperature raising	3.90	SS6
KS12	12	20-10-2017	17:20:00	20.10.2017	17:50:00	29.00	Problem occurred in operator	0.50	SS9
KS12	13	20-10-2017	18:40:00	20.10.2017	18:55:00	0.83	Water temperature raising	9.20	SS6
KS12	14	20-10-2017	20:30:00	20.10.2017	22:55:00	1.58	Water temperature raising	6.00	SS6
KS12	15	21-10-2017	19:15:00	21.10.2017	19:30:00	20.33	Water temperature raising	4.00	SS6
KS12	16	21-10-2017	21:30:00	21.10.2017	21:50:00	2.00	Water temperature raising	6.00	SS6
KS12	17	22-10-2017	14:00:00	22.10.2017	14:30:00	16.17	Water temperature raising	8.20	SS6
KS12	18	23-10-2017	10:00:00	23.10.2017	10:10:00	19.50	Water temperature raising	4.60	SS6
KS12	19	23-10-2017	19:00:46	23.10.2017	19:30:02	8.85	Engine oil temperature raising	2.00	SS6
KS12	20	25-10-2017	09:00:00	25.10.2017	09:15:00	37.50	Water temperature raising	5.90	SS6
KS12	21	25-10-2017	11:51:00	25.10.2017	14:55:00	2.60	Water temperature raising	4.07	SS6
KS12	22	25-10-2017	17:10:36	25.10.2017	19:15:16	2.26	Engine rpm not raising/lowering	2.08	SS6
KS12	23	26-10-2017	07:00:00	26.10.2017	15:30:30	11.75	Engine oil temperature raising	8.51	SS6
KS12	24	31-10-2017	18:00:00	31.10.2017	19:45:00	122.49	Hydraulic oil leakage	1.75	SS7
KS12	25	07-11-2017	19:45:00	07.11.2017	19:55:00	168.00	Initial problem (engine not starting)	2.00	SS5
KS12	26	09-11-2017	18:00:00	09.11.2017	20:45:00	46.08	Diesel leakage	2.75	SS6

KS12	27	24-11-2017	12:10:14	24.11.2017	12:15:00	351.42	Problem occurred in power tong	3.00	SS9
KS12	28	25-11-2017	16:00:00	25.11.2017	16:50:00	27.75	Hydraulic hose failed	1.80	SS7
KS12	29	06-12-2017	09:01:00	06.12.2017	09:50:00	256.18	Grease container empty	2.50	SS5
					MTBF of KS12	**59.38**	**MTTR of KS12**	**3.67**	
Systems	**No. of failures**	**Start Date**	**Start Time**	**End date**	**End Time**	**TBF, hrs**	**Reasons**	**TTR, hrs**	**Failure Codes**
BD13	1	02-10-2015	10:00:00	03-10-2015	23:00:00	0.00	Air lock/Steering hard	37.00	DS4/DS7
BD13	2	08-10-2015	17:20:00	08-10-2015	18:30:00	114.33	Pad bolts cut/Clutch setting	1.17	DS8/DS1
BD13	3	10-10-2015	18:10:00	10-10-2015	18:40:00	47.67	Body back door cut	0.50	DS8
BD13	4	13-10-2015	14:40:00	19-10-2015	17:00:00	68.00	Tipping body crack/Battery channel cut	146.33	DS8/DS4
BD13	5	19-10-2015	17:50:00	23-10-2015	17:00:00	0.83	Cabin door bend	95.17	DS8
BD13	6	02-11-2015	18:00:00	03-11-2015	14:00:00	241.00	Vacuum leak	20.00	DS5
BD13	7	22-11-2015	00:50:00	20-11-2015	03:00:00	442.83	King pin cut/Door lock cut	2.17	DS8/DS8
BD13	8	22-11-2015	21:00:00	20-11-2015	22:20:00	66.00	Front axil cut	1.33	DS8
BD13	9	22-11-2015	18:30:00	22-11-2015	19:00:00	44.17	Gear problem/Brake setting	0.50	DS3/DS1
BD13	10	30-11-2015	20:25:00	30-11-2015	21:40:00	193.42	Rear pad bolt loose	1.25	DS8
BD13	11	01-12-2015	21:00:00	01-12-2015	22:30:00	23.33	Ratchet replace/Gear problem	1.50	DS8/DS3
BD13	12	06-12-2015	07:00:00	13-12-2015	10:00:00	104.50	Cabin work	171.00	DS8
BD13	13	23-12-2015	19:45:00	23-12-2015	20:10:00	249.75	Front pad bolt loose	0.42	DS8
BD13	14	30-12-2015	12:00:00	30-12-2015	13:50:00	159.83	Steering oil/Steering hard/Brake problem	1.83	DS7/DS7/DS1
BD13	15	31-12-2015	19:25:00	01-01-2016	00:00:00	29.58	Rear pad cut/Self problem	4.58	DS8/DS4
BD13	16	02-01-2016	10:00:00	02-01-2016	15:30:00	34.00	Back dump body weld	5.50	DS8
BD13	17	04-01-2016	16:50:00	05-01-2016	11:00:00	49.33	Bumper weld/Cabin channel cut	18.17	DS8
BD13	18	06-01-2016	01:00:00	06-01-2016	01:30:00	14.00	Diesel pipe cut	0.50	DS8
BD13	19	07-01-2016	20:30:00	08-01-2016	13:30:00	43.00	Air lock problem/Centre bolt cut	17.00	DS5/DS8
BD13	20	08-01-2016	14:50:00	08-01-2016	15:45:00	1.33	Air lock problem	0.92	DS5
BD13	21	12-01-2016	12:30:00	12-01-2016	13:00:00	92.75	Brake setting/Accelerator spring cut	0.50	DS1/DS5
BD13	22	14-01-2016	00:15:00	14-01-2016	01:35:00	35.25	Head light	1.33	DS4
BD13	23	07-02-2016	20:00:00	08-02-2016	12:30:00	594.42	Brake problem/Front booster bolt/Self problem/Silencer weld	16.50	DS1/DS8/DS4/DS8
BD13	24	13-02-2016	23:30:00	15-02-2016	12:30:00	131.00	Self-starter problem	37.00	DS5
BD13	25	23-02-2016	16:00:00	23-02-2016	18:30:00	195.50	Low pickup	2.50	DS5
BD13	26	25-02-2016	09:00:00	26-02-2016	10:00:00	38.50	Tyre puncture	25.00	DS9

BD13	27	01-03-2016	18:00:00	01-03-2016	18:30:00	104.00	Steering uncontrolled	0.50	DS7
BD13	28	02-03-2016	15:00:00	02-03-2016	17:30:00	20.50	Tyre puncture	2.50	DS9
BD13	29	03-03-2016	12:50:00	02-03-2016	14:00:00	19.33	Clutch problem/Gear problem	1.17	DS1/DS3
BD13	30	07-03-2016	08:00:00	03-03-2016	15:00:00	114.00	Steering oil leak	7.00	DS7
BD13	31	07-03-2016	11:30:00	03-03-2016	12:00:00	92.50	Steering problem	0.50	DS7
BD13	32	09-03-2016	02:30:00	10-03-2016	16:00:00	134.50	Tipping problem/Self	37.50	DS6/DS4
BD13	33	11-03-2016	11:30:00	10-03-2016	16:30:00	19.50	Engine oil/Self/Alternator fail	5.00	DS5/DS4/DS5
BD13	34	16-03-2016	17:00:00	10-03-2016	23:00:00	144.50	Steering pump & bos replace	6.00	DS7
BD13	35	16-03-2016	08:00:00	10-03-2016	10:00:00	129.00	Engine oil service	2.00	DS5
BD13	36	12-03-2016	20:30:00	13-03-2016	02:00:00	58.50	Indicator	5.50	DS4
BD13	37	16-03-2016	17:00:00	16-03-2016	23:30:00	87.00	Steering gear problem/Steering pump problem	6.50	DS7/DS7
BD13	38	17-03-2016	06:00:00	18-03-2016	06:00:00	6.50	Cabin work	24.00	DS8
BD13	39	23-03-2016	06:30:00	23-03-2016	09:00:00	120.50	Self-problem	2.50	DS4
BD13	40	24-03-2016	06:00:00	25-03-2016	12:40:00	21.00	Self-problem	30.67	DS4
BD13	41	27-03-2016	11:30:00	27-03-2016	23:00:00	46.83	Fan belt cut/Dynamo baring jam	11.50	DS8/DS8
BD13	42	01-04-2016	00:00:00	02-04-2016	00:00:00	97.00	Engine work/Bogie shaft cut	24.00	DS5/DS8
BD13	43	02-04-2016	00:00:00	18-04-2016	16:30:00	0.00	Engine work/Bogie shaft cut	400.50	DS5/DS8
BD13	44	25-04-2016	06:00:00	25-04-2016	23:00:00	157.50	Self-Dynamo	17.00	DS4
BD13	45	02-05-2016	19:00:00	03-05-2016	14:00:00	164.00	Self-problem	19.00	DS4
BD13	46	03-05-2016	14:00:00	09-05-2016	21:00:00	0.00	Head gasket	151.00	DS5
BD13	47	11-05-2016	12:30:00	11-05-2016	17:00:00	39.50	Engine oil	4.50	DS5
BD13	48	11-05-2016	19:30:00	20-05-2016	10:00:00	2.50	Engine sound/Suspension bogie/Wheel bolt loose	206.50	DS5/DS6/DS8
BD13	49	22-05-2016	15:30:00	22-05-2016	18:30:00	53.50	Rear brake booster leak	3.00	DS1
BD13	50	25-05-2016	14:30:00	26-05-2016	01:30:00	68.00	Lift problem	11.00	DS6
BD13	51	09-06-2016	06:00:00	09-06-2016	17:00:00	340.50	Electrical work	11.00	DS4
BD13	52	09-06-2016	19:00:00	10-06-2016	13:15:00	2.00	Steering gear box problem	18.25	DS7
BD13	53	11-06-2016	18:30:00	12-06-2016	03:30:00	29.25	Steering hard	9.00	DS7
BD13	54	21-06-2016	05:00:00	21-06-2016	17:00:00	217.50	Air pipe cut	12.00	DS8
BD13	55	14-07-2016	14:00:00	28-07-2016	12:30:00	549.00	Low pickup/Air leak	334.50	DS5/DS5
BD13	56	06-08-2016	10:30:00	07-08-2016	09:00:00	214.00	Hydraulic oil leak/Wheel bolt/AC problem/Main glass	22.50	DS6/DS8/DS4/DS8
BD13	57	19-08-2016	06:00:00	19-08-2016	11:45:00	285.00	Centre bolt cut	5.75	DS8

BD13	58	25-08-2016	22:30:00	26-08-2016	16:30:00	154.75	Suspension work	18.00	DS6
BD13	59	27-08-2016	09:00:00	27-08-2016	15:00:00	16.50	Air pipe cut	6.00	DS8
BD13	60	28-08-2016	21:45:00	29-08-2016	12:30:00	30.75	Suspension work/FIP problem	14.75	DS6/DS8
BD13	61	05-09-2016	04:00:00	05-09-2016	20:30:00	159.50	Alternator problem/Self problem	16.50	DS5/DS4
BD13	62	15-09-2016	09:00:00	15-09-2016	23:30:00	228.50	Battery problem	14.50	DS4
BD13	63	17-09-2016	23:30:00	18-09-2016	05:00:00	48.00	Tyre puncture	5.50	DS9
BD13	64	19-09-2016	15:00:00	19-09-2016	18:00:00	34.00	Rear pad bolt cut	3.00	DS8
					MTBF of BD13	**109.75**	**MTTR of BD13**	**32.50**	
Systems	**No. of failures**	**Start Date**	**Start Time**	**End date**	**End Time**	**TBF, hrs**	**Reasons**	**TTR, hrs**	**Failure Codes**
BD14	1	01-10-2015	01:00:00	02-10-2015	12:10:00	0.00	Shackle pin failure/Steering oil/Head light	35.17	DS8/DS7/DS4
BD14	2	03-10-2015	09:30:00	03-10-2015	14:45:00	21.33	Clutch problem/Gear problem	5.25	DS1/DS3
BD14	3	06-10-2015	08:30:00	06-10-2015	10:30:00	65.75	Front shackle pin cut	2.00	DS8
BD14	4	06-10-2015	17:30:00	06-10-2015	19:00:00	7.00	Shackle pin cut/Silencer cut	1.50	DS8/DS8
BD14	5	08-10-2015	06:00:00	08-10-2015	09:40:00	35.00	Silencer pipe cut	3.67	DS8
BD14	6	11-10-2015	06:00:00	11-10-2015	07:00:00	68.33	Driver seat belt cut	1.00	DS8
BD14	7	11-10-2015	17:00:00	12-10-2015	14:00:00	10.00	Centre bolt cut	21.00	DS8
BD14	8	21-10-2015	18:00:00	21-10-2015	18:30:00	220.00	Suspension work/Steering oil leak	0.50	DS6/DS7
BD14	9	27-10-2015	14:15:00	27-10-2015	17:00:00	139.75	Front u clamp cut	2.75	DS7
BD14	10	31-10-2015	18:30:00	01-11-2015	00:00:00	97.50	Cabin door hinges cut	5.50	DS7
BD14	11	01-11-2015	06:00:00	02-11-2015	06:00:00	6.00	Alternator failure	24.00	DS4
BD14	12	02-11-2015	06:00:00	03-11-2015	15:10:00	0.00	Cabin door cut	33.17	DS8
BD14	13	07-11-2015	16:00:00	07-11-2015	17:40:00	96.83	Centre bolt cut/Lift bed cut	1.67	DS8/DS8
BD14	14	12-11-2015	17:50:00	13-11-2015	17:00:00	120.17	UJ cross cut/Head light	23.17	DS8/DS4
BD14	15	23-11-2015	20:50:00	23-11-2015	21:20:00	243.83	Shackle pin cut	0.50	DS8
BD14	16	25-11-2015	00:15:00	25-11-2015	01:15:00	26.92	Suspension work/Steering oil leak	1.00	DS6
BD14	17	27-11-2015	05:30:00	27-11-2015	06:15:00	52.25	Body doom lock/Brake setting	0.75	DS8/DS1
BD14	18	19-11-2015	16:45:00	19-11-2015	17:20:00	181.50	Shackle pin cut	0.58	DS8
BD14	19	30-11-2015	07:00:00	30-11-2015	08:10:00	253.67	Self-problem	1.17	DS4
BD14	20	01-12-2015	21:30:00	02-12-2015	21:30:00	37.33	Vacuum leak/Battery pole cut/Head light	24.00	DS8/DS4/DS4
BD14	21	02-12-2015	21:30:00	03-12-2015	17:00:00	0.00	Engine over heat/Steering uncontrolled/Gear problem/Cabin bracket cut//Head light	19.50	DS5/DS7/DS3/DS8/ DS4
BD14	22	12-12-2015	18:10:00	12-12-2015	19:19:00	217.17	Air lock problem	1.15	DS5

BD14	23	12-12-2015	23:25:00	13-12-2015	00:30:00	4.10	Suspension work/Cabin bracket cut/Steering uncontrolled/Self	1.08	DS6/DS8/DS7/DS4
BD14	24	16-12-2015	08:15:00	16-12-2015	09:30:00	79.75	Alternator problem/Steering oil leak	1.25	DS4/DS7
BD14	25	17-12-2015	06:00:00	17-12-2015	09:00:00	20.50	Air lock problem	3.00	DS5
BD14	26	19-12-2015	18:40:00	20-12-2015	20:50:00	57.67	Shackle pin cut	26.17	DS8
BD14	27	22-12-2015	00:15:00	22-12-2015	00:45:00	27.42	Rear centre bolt cut/Brake setting	0.50	DS8/DS1
BD14	28	28-12-2015	00:05:00	29-12-2015	01:20:00	143.33	Suspension work	25.25	DS6
BD14	29	30-12-2015	20:10:00	30-12-2015	23:30:00	42.83	Rear hub axle stud cut	3.33	DS8
BD14	30	02-01-2016	16:15:00	03-01-2016	21:30:00	64.75	Head light	29.25	DS4
BD14	31	05-01-2016	00:30:00	05-01-2016	01:30:00	27.00	Front ratchet cut	1.00	DS8
BD14	32	07-01-2016	20:30:00	08-01-2016	18:15:00	67.00	Suspension work	21.75	DS6
BD14	33	14-01-2016	04:00:00	14-01-2016	04:20:00	129.75	Lift bed welding	0.33	DS8
BD14	34	16-01-2016	20:05:00	16-01-2016	21:30:00	63.75	Engine bedding cut	1.42	DS8
BD14	35	18-01-2016	19:35:00	18-01-2016	20:35:00	46.08	Head light	1.00	DS4
BD14	36	30-01-2016	17:30:00	30-01-2016	17:45:00	284.92	Head light	0.25	DS4
BD14	37	10-02-2016	07:30:00	10-02-2016	10:00:00	253.75	Front shackle pin cut/Housing oil in engine	2.50	DS8/DS5
BD14	38	16-02-2016	11:45:00	16-02-2016	13:30:00	145.75	Lift problem	1.75	DS6
BD14	39	17-02-2016	11:30:00	17-02-2016	15:30:00	22.00	Front shackle pin cut/Self problem	4.00	DS8/DS4
BD14	40	26-02-2016	10:00:00	27-02-2016	16:00:00	210.50	Axle studs cut/Suspension work	30.00	DS8/DS6
BD14	41	01-03-2016	22:00:00	02-03-2016	09:30:00	78.00	Engine speed reduced	11.50	DS5
BD14	42	05-03-2016	07:00:00	05-03-2016	13:30:00	69.50	Air lock problem/Self problem	6.50	DS5/DS4
BD14	43	07-03-2016	07:00:00	07-03-2016	08:00:00	41.50	Clutch problem	1.00	DS1
BD14	44	08-03-2016	06:00:00	08-03-2016	13:00:00	22.00	Engine oil service	7.00	DS5
BD14	45	09-03-2016	05:00:00	09-03-2016	14:00:00	16.00	Engine raise/Clutch setting	9.00	DS5/DS1
BD14	46	03-03-2016	06:00:00	03-03-2016	07:00:00	152.00	Air lock	1.00	DS5
BD14	47	06-03-2016	08:00:00	06-03-2016	12:30:00	73.00	Steering hard	4.50	DS7
BD14	48	10-03-2016	13:00:00	10-03-2016	14:10:00	96.50	Diesel leak	1.17	DS8
BD14	49	10-03-2016	14:10:00	10-03-2016	15:00:00	0.00	Engine oil	0.83	DS5
BD14	50	10-03-2016	22:00:00	11-03-2016	02:00:00	7.00	Air lock problem	4.00	DS5
BD14	51	12-03-2016	20:30:00	13-03-2016	01:30:00	42.50	Head light	5.00	DS4
BD14	52	17-03-2016	18:00:00	17-03-2016	19:00:00	112.50	Head light	1.00	DS4
BD14	53	17-03-2016	23:45:00	18-03-2016	06:00:00	4.75	Steering hard/Head light/Helper seat cut	6.25	DS7/DS4/DS8

BD14	54	21-03-2016	12:00:00	21-03-2016	14:00:00	78.00	Tyre puncture	2.00	DS9
BD14	55	24-03-2016	07:30:00	24-03-2016	17:30:00	65.50	Radiator hose damage	10.00	DS5
BD14	56	26-03-2016	14:45:00	26-03-2016	16:30:00	45.25	Engine over heat/Brake setting/Silencer weld	1.75	DS5/DS1/DS8
BD14	57	28-03-2016	18:00:00	30-03-2016	06:00:00	49.50	Gear box bell housing cut/Wiring short	36.00	DS3/DS4
BD14	58	01-04-2016	06:00:00	01-04-2016	14:00:00	48.00	Brake setting/Steering problem	8.00	DS1/DS7
BD14	59	05-04-2016	00:00:00	05-04-2016	14:00:00	82.00	Silencer cut	14.00	DS8
BD14	60	08-04-2016	06:00:00	08-04-2016	07:00:00	64.00	Gear problem	1.00	DS3
BD14	61	10-04-2016	13:30:00	10-04-2016	18:00:00	54.50	Gear problem	4.50	DS3
BD14	62	16-04-2016	04:00:00	16-04-2016	17:30:00	130.00	Gear hard	13.50	DS3
BD14	63	18-04-2016	06:00:00	19-04-2016	06:00:00	36.50	Shackle pin cut	24.00	DS8
BD14	64	30-04-2016	09:00:00	30-04-2016	16:00:00	267.00	Accelerator paddle/Engine oil/Hydraulic oil	7.00	DS8/DS5/DS6
BD14	65	01-05-2016	00:00:00	07-05-2016	20:30:00	8.00	Engine work	164.50	DS5
BD14	66	11-05-2016	08:00:00	12-05-2016	15:30:00	83.50	Wiring short	31.50	DS4
BD14	67	12-05-2016	21:30:00	15-05-2016	18:00:00	6.00	Electrical work	68.50	DS4
BD14	68	19-05-2016	21:30:00	21-05-2016	17:30:00	99.50	Lift pipe cut	44.00	DS6
BD14	69	26-05-2016	10:20:00	26-05-2016	15:00:00	112.83	Air lock/Self	4.67	DS5/DS4
BD14	70	26-05-2016	20:35:00	28-05-2016	15:00:00	5.58	Engine replace/Shackle pin cut	42.42	DS5/DS8
BD14	71	31-05-2016	23:00:00	01-06-2016	00:00:00	80.00	Tipping problem	1.00	DS6
BD14	72	01-06-2016	06:00:00	01-06-2016	19:00:00	6.00	Lift problem	13.00	DS3
BD14	73	02-06-2016	15:00:00	02-06-2016	22:00:00	20.00	Gear box problem	7.00	DS3
BD14	74	03-06-2016	12:00:00	06-06-2016	12:35:00	14.00	Electrical work	72.58	DS4
BD14	75	06-06-2016	22:30:00	07-06-2016	11:30:00	9.92	Lift problem	13.00	DS6
BD14	76	21-06-2016	05:00:00	21-06-2016	12:00:00	329.50	Lift pump fail/Gear box sound	7.00	DS6/DS3
BD14	77	23-06-2016	06:00:00	23-06-2016	19:00:00	42.00	Self-problem	13.00	DS4
BD14	78	25-06-2016	08:00:00	25-06-2016	14:30:00	37.00	Self-problem	6.50	DS4
BD14	79	01-08-2016	01:00:00	01-08-2016	18:00:00	874.50	Engine over heat/Fan belt cut/AC belt cut	17.00	DS5/DS8/DS8
BD14	80	02-08-2016	03:30:00	05-08-2016	12:00:00	9.50	Cabin door repair	80.50	DS8
BD14	81	06-08-2016	19:00:00	07-08-2016	14:20:00	31.00	Suspension work	19.33	DS6
BD14	82	09-08-2016	12:30:00	09-08-2016	14:30:00	46.17	Pad bolt cut	2.00	DS8
BD14	83	11-08-2016	14:00:00	11-08-2016	21:30:00	47.50	Rear pad bolt cut	7.50	DS8
BD14	84	11-08-2016	23:00:00	14-08-2016	10:00:00	1.50	Clutch problem/Pad bolts cut	59.00	DS1/DS8
BD14	85	01-09-2016	16:00:00	02-09-2016	21:00:00	438.00	AC gas/Steering oil leak	29.00	DS4/DS7

BD14	86	04-09-2016	02:00:00	04-09-2016	11:30:00	29.00	Steering problem	9.50	DS7
BD14	87	11-09-2016	10:00:00	11-09-2016	13:50:00	166.50	Suspension work	3.83	DS6
BD14	88	21-09-2016	01:30:00	21-09-2016	07:00:00	227.67	Suspension work	5.50	DS6
					MTBF of BD14	**90.36**	**MTTR of BD14**	**14.38**	
Systems	**No. of failures**	**Start Date**	**Start Time**	**End date**	**End Time**	**TBF, hrs**	**Reasons**	**TTR, hrs**	**Failure Codes**
BD15	1	03-10-2015	06:00:00	04-10-2015	19:00:00	0	Suspension work	37	DS6
BD15	2	06-10-2015	15:40:00	06-10-2015	17:30:00	44.67	Radiator boil	1.83	DS5
BD15	3	10-10-2015	18:00:00	10-10-2015	18:45:00	96.5	Rear shackle pin cut	0.75	DS8
BD15	4	14-10-2015	00:30:00	14-10-2015	11:50:00	77.75	Centre bolt cut/Steering problem	11.33	DS8/DS7
BD15	5	14-10-2015	20:05:00	14-10-2015	20:35:00	8.25	Gear not work	0.5	DS3
BD15	6	17-10-2015	18:00:00	18-10-2015	06:00:00	69.42	Cabin door welding	12	DS8
BD15	7	26-10-2015	18:30:00	26-10-2015	19:00:00	204.5	Cam bush/Head light/Driver seat	0.5	DS3/DS4/DS8
BD15	8	27-10-2015	07:20:00	26-10-2015	08:30:00	12.33	Air lock problem/Head light	1.17	DS5/DS4
BD15	9	03-11-2015	15:00:00	04-11-2015	19:30:00	198.5	Rear hub problem/Air leak/Indicator/Silencer weld	28.5	DS8/DS5/DS4/DS8
BD15	10	09-11-2015	18:00:00	09-11-2015	18:25:00	118.5	Accelerator lock cut/Self problem	0.42	DS8/DS4
BD15	11	18-11-2015	19:40:00	18-11-2015	22:30:00	217.25	Self/Head light	2.83	DS4/DS4
BD15	12	21-11-2015	11:30:00	20-11-2015	15:50:00	61	Joint cut	4.33	DS8
BD15	13	21-11-2015	21:00:00	20-11-2015	22:30:00	29.17	Head light/Cabin switch	1.5	DS4/DS8
BD15	14	22-11-2015	07:30:00	22-11-2015	20:00:00	33	Accelerator problem/Air tank cut/Head light	12.5	DS5/DS8/DS4
BD15	15	03-12-2015	18:20:00	04-12-2015	17:30:00	262.33	Torque rod bush/Engine bedding	23.17	DS2/DS5
BD15	16	04-12-2015	19:00:00	04-12-2015	21:45:00	1.5	Door lock/Dash weld	2.75	DS8/DS8
BD15	17	11-12-2015	11:30:00	11-12-2015	15:00:00	157.75	Air lock problem	3.5	DS5
BD15	18	12-12-2015	23:20:00	13-12-2015	01:10:00	32.33	Joint bolt loose/Engine bedding/Self-Battery	1.83	DS5/DS5/DS4
BD15	19	13-12-2015	22:20:00	14-12-2015	11:30:00	21.17	Suspension work	13.17	DS6
BD15	20	15-12-2015	03:25:00	15-12-2015	04:30:00	15.92	Cabin bedding bolt loose/Sub frame cut	1.08	DS8/DS8
BD15	21	16-12-2015	20:30:00	16-12-2015	22:20:00	40	Joint bolt loose/Engine bedding bolt loose	1.83	DS8/DS8
BD15	22	20-12-2015	12:15:00	20-12-2015	14:30:00	85.92	Brake problem/Joint cut	2.25	DS1/DS8
BD15	23	26-12-2015	20:00:00	27-12-2015	00:30:00	149.5	CJ rubber cut/Steering hard/Suspension work/Self problem	4.5	DS8/DS7/DS6/DS4
BD15	24	27-12-2015	08:00:00	27-12-2015	15:30:00	7.5	Rear bedding cut	7.5	DS8
BD15	25	30-12-2015	08:15:00	01-01-2016	00:00:00	64.75	Suspension work	39.75	DS6

BD15	26	01-01-2016	00:00:00	02-01-2016	09:45:00	0	Suspension work/Engine over heat	33.75	DS6/DS5
BD15	27	03-01-2016	08:00:00	05-01-2016	00:40:00	22.25	Axle bolt loose/Head light	40.67	DS8/DS4
BD15	28	05-01-2016	17:40:00	06-01-2016	04:15:00	17	Steering problem/Clutch problem	10.58	DS7/DS1
BD15	29	06-01-2016	17:50:00	06-01-2016	19:00:00	13.58	Engine oil leak/Brake setting/Steering hard/Wheel sound	1.17	DS5/DS1/DS3/DS8
BD15	30	07-01-2016	20:30:00	09-01-2016	22:30:00	25.5	Steering pump fail/Clutch problem	50	DS7/DS1
BD15	31	12-01-2016	00:10:00	12-01-2016	11:00:00	49.67	Steering hard/Suspension work	10.83	DS7/DS6
BD15	32	14-01-2016	13:00:00	14-01-2016	19:00:00	50	Air lock problem	6	DS5
BD15	33	24-01-2016	00:30:00	24-01-2016	01:45:00	221.5	Engine bedding bolt loose/Clutch rod bend/Steering hard/Accelerator problem	1.25	DS5/DS1/DS7/DS5
BD15	34	24-01-2016	16:00:00	26-01-2016	19:15:00	14.25	Radiator leak	51.25	DS5
BD15	35	27-01-2016	20:25:00	29-01-2016	09:45:00	25.17	Radiator leak	37.33	DS5
BD15	36	07-02-2016	08:10:00	03-02-2016	08:25:00	214.42	Rear pad cut	0.25	DS8
BD15	37	11-02-2016	21:50:00	04-02-2016	16:00:00	205.42	Suspension work	18.17	DS6
BD15	38	11-02-2016	10:40:00	11-02-2016	11:30:00	162.67	Battery pole cut	0.83	DS4
BD15	39	15-02-2016	07:45:00	15-02-2016	10:00:00	92.25	Self-problem	2.25	DS4
BD15	40	01-03-2016	00:00:00	09-03-2016	14:00:00	350	Engine work	206	DS5
BD15	41	11-03-2016	16:00:00	12-03-2016	12:30:00	50	Engine over heat	20.5	DS5
BD15	42	15-03-2016	20:00:00	15-03-2016	23:45:00	79.5	Air leak	3.75	DS5
BD15	43	16-03-2016	06:00:00	15-03-2016	13:00:00	6.25	Gear problem	7	DS3
BD15	44	17-03-2016	17:45:00	17-03-2016	18:45:00	52.75	Air leak/Battery pole	1	DS5/DS4
BD15	45	28-03-2016	06:00:00	28-03-2016	10:00:00	251.25	Air pipe cut/Rear door lock cut	4	DS8/DS8
BD15	46	30-03-2016	10:00:00	30-03-2016	22:00:00	48	Clutch problem	12	DS1
BD15	47	01-04-2016	06:00:00	01-04-2016	11:00:00	32	Engine oil leak	5	DS5
BD15	48	03-04-2016	10:00:00	04-04-2016	10:00:00	47	Bogie bolt cut/Pad bolt cut	24	DS8/DS8
BD15	49	04-04-2016	10:00:00	05-04-2016	13:00:00	0	Bogie bolt cut/Pad bolt cut	27	DS8/DS8
BD15	50	07-04-2016	23:00:00	08-04-2016	01:00:00	58	Rear joint cut	2	DS8
BD15	51	09-04-2016	18:00:00	12-04-2016	22:00:00	41	Bogie suspension work	76	DS6
BD15	52	18-04-2016	06:00:00	19-04-2016	11:00:00	128	Camshaft cut	29	DS8
BD15	53	28-04-2016	03:00:00	29-04-2016	03:00:00	208	Wheel bolt cut	24	DS8
BD15	54	30-04-2016	03:00:00	01-04-2016	00:00:00	24	Wheel bolt cut	45	DS8
BD15	55	21-04-2016	06:00:00	21-04-2016	16:00:00	486	Engine oil/Electrical work	10	DS5/DS4
BD15	56	04-05-2016	02:00:00	06-05-2016	19:00:00	298	Suspension work	65	DS6

BD15	57	12-05-2016	06:00:00	12-05-2016	11:30:00	131	Diesel filter bracket cut	5.5	DS8
BD15	58	25-05-2016	10:00:00	26-05-2016	08:15:00	310.50	Diesel tank cap/Electrical work	22.25	DS8/DS4
BD15	59	26-05-2016	22:00:00	28-05-2016	11:00:00	13.75	Main glass damage	37	DS8
BD15	60	30-05-2016	06:00:00	30-05-2016	11:00:00	43	Self-problem	5	DS4
BD15	61	03-06-2016	06:00:00	03-06-2016	16:00:00	91	Electrical work	10	DS4
BD15	62	04-06-2016	10:00:00	04-06-2016	14:00:00	18	Suspension work	4	DS6
BD15	63	04-06-2016	14:00:00	04-06-2016	14:00:00	0	Back door work	0	DS8
BD15	64	06-06-2016	10:00:00	06-06-2016	12:00:00	44	Lift problem	2	DS6
BD15	65	07-06-2016	22:00:00	08-06-2016	01:30:00	34	Battery pole cut/Head light	3.5	DS8/DS4
BD15	66	08-06-2016	22:00:00	09-06-2016	16:00:00	20.5	Vacuum leak/Battery pole cut/Head light	18	DS5/DS4/DS4
BD15	67	09-06-2016	16:00:00	09-06-2016	17:00:00	0	Tyre puncture	1	DS9
BD15	68	11-06-2016	22:30:00	12-06-2016	09:00:00	53.5	Battery pole cut	10.5	DS4
BD15	69	12-06-2016	23:00:00	13-06-2016	09:00:00	14	Self-problem/Diesel leak	10	DS4/DS8
BD15	70	20-06-2016	21:15:00	21-06-2016	11:50:00	180.25	Steering hose cut/Diesel main pipe cut/Air leak	14.58	DS7/DS8/DS5
BD15	71	23-06-2016	18:00:00	23-06-2016	18:30:00	54.17	Steering oil	0.5	DS7
BD15	72	26-06-2016	14:15:00	26-06-2016	17:15:00	67.75	Air leak	3	DS5
BD15	73	10-08-2016	10:00:00	10-08-2016	13:30:00	1072.75	Suspension work	3.5	DS6
BD15	74	20-08-2016	08:15:00	20-08-2016	16:00:00	234.75	Suspension work	7.75	DS6
BD15	75	09-09-2016	23:30:00	10-09-2016	02:00:00	487.5	Vacuum leak/Booster clamp cut	2.5	DS5/DS8
BD15	76	15-09-2016	06:00:00	15-09-2016	13:00:00	124	Suspension work	7	DS6
BD15	77	23-09-2016	19:30:00	23-09-2016	23:00:00	198.5	Engine over heat	3.5	DS5
					MTBF of BD15	**110.08**	**MTTR of BD15**	**15.76**	
Systems	**No. of failures**	**Start Date**	**Start Time**	**End date**	**End Time**	**TBF, hrs**	**Reasons**	**TTR, hrs**	**Failure Codes**
KD16	1	04-10-2015	06:00:00	04-10-2015	13:30:00	0	Vacuum leak/Gear oil/Steering hard/Body pin/Cabin door	7.5	DS5/DS3/DS7/DS8/DS8
KD16	2	04-11-2015	07:00:00	26-11-2015	22:00:00	737.5	Lift problem/Lift ramp cylinder	543	DS6/DS6
KD16	3	03-12-2015	18:00:00	11-12-2015	18:00:00	164	Bogie suspension work	192	DS6
KD16	4	22-12-2015	16:00:00	22-12-2015	18:00:00	262	Battery pole cut	2	DS4
KD16	5	27-12-2015	18:00:00	28-12-2015	15:00:00	120	Suspension work/Torque rod bush	21	DS6/DS2
KD16	6	25-01-2016	19:20:00	26-01-2016	14:00:00	676.33	Wheel bolt cut	18.67	DS8
KD16	7	16-02-2016	18:00:00	17-02-2016	18:30:00	508	Housing bolt	24.5	DS7

KD16	8	07-03-2016	08:00:00	08-03-2016	16:00:00	445.5	Torque rod bush/Engine bedding	32	DS2/DS5
KD16	9	01-04-2016	10:20:00	02-04-2016	10:20:00	570.33	Gear box problem	24	DS3
KD16	10	11-04-2016	06:30:00	11-04-2016	10:00:00	212.17	Fan leaf cut/Engine bedding cut	3.5	DS5/DS5
KD16	11	11-04-2016	19:30:00	22-04-2016	13:00:00	9.5	Balance rod bush/Engine bedding/Radiator fan cut	257.5	DS2/DS5/DS5
KD16	12	30-04-2016	18:00:00	01-05-2016	00:00:00	197	Tyre puncture	6	DS9
KD16	13	01-05-2016	00:00:00	01-05-2016	18:30:00	0	Tyre puncture	18.5	DS9
KD16	14	19-05-2016	16:50:00	01-06-2016	00:00:00	430.33	Body pin cut/Wheel bolt/Suspension work/Torque rod bush	295.17	DS8/DS8/DS6/DS2
KD16	15	28-06-2016	13:00:00	28-06-2016	15:40:00	661	Nozzle hose leak	2.67	DS5
KD16	16	04-07-2016	08:00:00	04-07-2016	11:45:00	136.33	Steering hard/Head light-Dynamo not work	3.75	DS7/DS4
KD16	17	11-07-2016	17:30:00	11-07-2016	20:00:00	173.75	Suspension work	2.5	DS6
KD16	18	03-08-2016	17:30:00	04-08-2016	16:30:00	549.5	Suspension work	23	DS6
KD16	19	26-08-2016	11:30:00	27-08-2016	17:00:00	523	Steering hard	29.5	DS7
KD16	20	01-09-2016	09:00:00	03-09-2016	13:00:00	112	Body pin cut/Silencer weld	52	DS8/DS8
					MTBF of KD16	**324.4125**	**MTTR of KD16**	**77.9375**	
Systems	**No. of failures**	**Start Date**	**Start Time**	**End date**	**End Time**	**TBF, hrs**	**Reasons**	**TTR, hrs**	**Failure Codes**
KD17	1	08-10-2015	14:00:00	09-10-2015	15:15:00	0	Hydraulic oil leak/Wheel bolt/AC problem/Main glass	25.25	DS6/DS8/DS4/DS8
KD17	2	14-11-2015	05:30:00	14-11-2015	17:00:00	854.25	Wheel jam/Battery pole cut	11.5	DS8/DS4
KD17	3	26-11-2015	09:00:00	28-11-2015	13:30:00	280	Bogie suspension work	52.5	DS6
KD17	4	01-12-2015	18:00:00	02-12-2015	14:00:00	76.5	Lift problem	20	DS6
KD17	5	06-12-2015	13:00:00	06-12-2015	16:00:00	95	Lift problem	3	DS6
KD17	6	23-12-2015	17:15:00	24-12-2015	12:40:00	409.25	Diesel tank bracket cut/Engine bell housing/Wiring	19.42	DS8/DS5/DS4
KD17	7	02-01-2016	17:25:00	20-01-2016	14:00:00	220.75	Bogie shaft cut/Brake cam shaft/Air leak/Ratchet/Engine oil/Cabin door/Silencer weld	410.58	DS8/DS8/DS5/DS3/DS5/DS8/DS8
KD17	8	03-02-2016	18:45:00	04-02-2016	21:30:00	340.75	Suspension work/Rivers gear check	26.75	DS6/DS3
KD17	9	14-02-2016	19:30:00	15-02-2016	19:00:00	238	Engine oil leak/Cabin door problem	23.5	DS5/DS8
KD17	10	16-03-2016	14:30:00	17-03-2016	10:00:00	715.5	Steering oil leak	19.5	DS7
KD17	11	06-04-2016	13:00:00	07-04-2016	12:45:00	483	Suspension work	23.75	DS6
KD17	12	02-05-2016	10:45:00	03-05-2016	11:00:00	598	Main plate cut	24.25	DS8
KD17	13	24-05-2016	17:00:00	26-05-2016	11:00:00	510	Bogie hub play/Wheel bolt missing	42	DS8/DS8

KD17	14	15-06-2016	17:30:00	16-06-2016	17:30:00	486.5	Axle studs cut/Suspension work	24	DS8/DS6
KD17	15	17-06-2016	17:00:00	01-07-2016	00:00:00	23.5	Steering hard/Torque rod bush/Bogie hub cut	342.5	DS7/DS2/DS8
KD17	16	02-07-2016	16:00:00	22-07-2016	17:30:00	40	Steering hard/Torque rod bush/Bogie hub cut	481.5	DS7/DS2/DS8
KD17	17	03-08-2016	12:50:00	04-08-2016	12:50:00	283.33	Tyre burst/Suspension work	24	DS9/DS6
KD17	18	05-08-2016	01:50:00	04-08-2016	20:00:00	13	PTO fail/Clutch replace/Suspension work	7.17	DS8/DS1/DS6
KD17	19	03-09-2016	17:30:00	04-09-2016	11:00:00	717.5	Diesel tank bracket cut	17.5	DS8
					MTBF of KD17	**336.04**	**MTTR of KD17**	**84.14**	
Systems	**No. of failures**	**Start Date**	**Start Time**	**End date**	**End Time**	**TBF, hrs**	**Reasons**	**TTR, hrs**	**Failure Codes**
KD18	1	01-10-2015	17:40:00	14-10-2015	18:40:00	0	Bell housing cut/Silencer pipe cut	313	DS8/DS8
KD18	2	01-11-2015	13:20:00	02-11-2015	16:00:00	426.67	Low pickup	26.67	DS5
KD18	3	10-11-2015	10:00:00	10-11-2015	17:00:00	186	Brake problem/Door glass	7	DS1/DS8
KD18	4	19-11-2015	20:00:00	20-11-2015	17:00:00	219	Gear problem/Clutch booster	21	DS3/DS1
KD18	5	20-11-2015	22:15:00	21-11-2015	19:40:00	5.25	Clutch problem	21.42	DS1
KD18	6	31-12-2015	11:30:00	31-12-2015	14:00:00	951.83	Tyre repair	2.5	DS9
KD18	7	11-01-2016	16:00:00	12-01-2016	06:00:00	266	Hydraulic oil leak/Wheel bolt/AC problem/Main glass	14	DS6/DS8/DS4/DS8
KD18	8	24-01-2016	15:00:00	25-01-2016	15:00:00	297	Diesel tank bracket cut/Engine bell housing/Wiring	24	DS8/DS5/DS4
KD18	9	28-01-2016	08:00:00	29-01-2016	17:00:00	65	Bogie shaft cut	33	DS2
KD18	10	09-02-2016	06:00:00	09-02-2016	12:45:00	253	Engine over heat/Fan belt cut/AC belt cut	6.75	DS5/DS8/DS4
KD18	11	15-02-2016	09:30:00	15-02-2016	16:00:00	140.75	Front shackle pin cut/Steering oil	6.5	DS8/DS7
KD18	12	08-03-2016	21:30:00	09-03-2016	08:00:00	533.5	Head light	10.5	DS4
KD18	13	12-03-2016	07:00:00	12-03-2016	13:30:00	71	Clutch problem	6.5	DS1
KD18	14	13-03-2016	06:00:00	13-03-2016	18:00	16.5	Clutch problem/Self problem	12	DS1/DS4
KD18	15	07-04-2016	12:30:00	07-04-2016	17:45:00	594.5	Diesel tank WELDING	5.25	DS8
KD18	16	16-04-2016	18:00:00	17-04-2016	14:00:00	216.25	Engine signal	20	DS5
KD18	17	24-04-2016	18:15:00	25-04-2016	12:30:00	172.25	Suspension work	18.25	DS6
KD18	18	03-05-2016	19:00:00	04-05-2016	15:00:00	198.5	Suspension work	20	DS6
KD18	19	24-05-2016	11:00:00	24-05-2016	16:30:00	476	Suspension work/Diesel tank bracket	5.5	DS6/DS8
KD18	20	08-06-2016	17:15:00	09-06-2016	13:00:00	360.75	Bogie shaft cut	19.75	DS2
KD18	21	21-06-2016	12:25:00	23-06-2016	12:00:00	287.42	Body pin channel crack	47.58	DS8

KD18	22	13-07-2016	08:00:00	14-07-2016	17:30:00	476	Tyre repair/ A/C AC not working	33.5	DS9/DS4
KD18	23	31-07-2016	12:15:00	31-07-2016	16:00:00	402.75	Clutch fail	3.75	DS1
KD18	24	01-08-2016	17:00:00	02-08-2016	16:00:00	25	Head light	23	DS4
KD18	25	20-08-2016	16:30:00	01-09-2016	00:00:00	432.5	Suspension work/Door problem	271.5	DS6/DS8
KD18	26	01-09-2016	00:00:00	01-09-2016	08:00:00	0	Suspension work	8	DS6
KD18	27	05-09-2016	11:00:00	05-09-2016	18:00:00	99	Diesel tank leak/RPM raise	7	DS8/DS5
					MTBF of KD18	**265.65**	**MTTR of KD18**	**36.59**	

Table A.3 Failure and repair data of various subsystems of shovel and dumper in surface limestone mine

Systems	**No. of failures**	**Start Date**	**Start Time**	**End date**	**End Time**	**TBF, hrs**	**Reasons**	**TTR, hrs**	**Failure Codes**
KS19	1	12-04-2017	16:30:00	12-04-2017	16:35:00	0.00	Bucket hoisting problem	0.08	SS7
KS19	2	26-04-2017	15:45:00	26-04-2017	15:50:00	335.17	Foot step ladder damaged	0.08	SS4
KS19	3	03-05-2017	19:00:00	03-05-2017	19:30:00	171.17	Grease container empty	0.5	SS7
KS19	4	18-05-2017	17:15:00	18-05-2017	18:15:00	357.75	Grease pressure switch problem	1	SS5
KS19	5	24-05-2017	16:30:00	24-05-2017	16:45:00	142.25	Hydraulic hose failed	0.25	SS7
KS19	6	04-06-2017	15:30:00	04-06-2017	19:00:00	262.75	Initial problem (engine not starting)	3.5	SS6
KS19	7	07-06-2017	09:01:00	07-06-2017	10:00:00	62.02	Foot step ladder damaged	0.98	SS4
KS19	8	16-06-2017	19:10:00	16-06-2017	19:40:00	225.17	Electrical breakdown	0.5	SS5
KS19	9	26-06-2017	23:45:00	26-06-2017	23:55:00	244.08	Grease pump not working	0.17	SS7
KS19	10	27-06-2017	01:30:00	27-06-2017	02:00:00	1.58	Horn problem	0.5	SS5
KS19	11	05-07-2017	11:35:00	05-07-2017	17:15:00	201.58	Hydraulic oil leakage	5.67	SS7
KS19	12	08-07-2017	04:06:35	08-07-2017	04:50:39	58.86	Grease hose failed in boom cylinder	0.73	SS2
KS19	13	08-07-2017	05:00:36	08-07-2017	05:15:28	0.17	Grease hose failed in boom cylinder	0.25	SS2
KS19	14	08-07-2017	08:30:01	08-07-2017	09:30:00	3.24	Grease hose failed in arm Cylinder	1	SS1
KS19	15	15-07-2017	08:16:00	15-07-2017	10:30:00	166.77	Grease hose failed in boom cylinder	2.23	SS2
KS19	16	15-07-2017	11:47:47	15-07-2017	12:00:00	1.30	Bucket operations slow	0.2	SS7
KS19	17	17-07-2017	09:00:00	17-07-2017	09:01:00	45.00	Bucket changing work	0.02	SS3
KS19	18	28-07-2017	14:55:00	28-07-2017	17:00:00	269.90	Grease container empty	2.08	SS7
KS19	19	03-08-2017	11:01:00	03-08-2017	17:30:44	138.02	Grease pump not working	6.5	SS7
KS19	20	04-08-2017	08:11:00	04-08-2017	08:30:00	14.67	Ladders and Railings	0.32	SS4
KS19	21	14-08-2017	20:30:00	14-08-2017	22:00:00	252.00	Water leak from water pump seal	1.5	SS6

KS19	22	30-08-2017	07:30:03	31-08-2017	01:00:00	369.50	Bucket changing work	17.5	SS3
KS19	23	08-09-2017	12:00:00	08-09-2017	13:25:00	203.00	Grease hose failed in arm Cylinder	1.42	SS1
KS19	24	25-09-2017	20:30:00	25-09-2017	21:30:00	415.08	Hydraulic oil level is more	1	SS7
KS19	25	07-10-2017	08:01:00	07-10-2017	09:20:00	274.52	Grease hose failed in arm Cylinder	1.32	SS2
KS19	26	09-10-2017	00:15:00	09-10-2017	00:45:00	38.92	Hydraulic oil leakage	0.5	SS7
KS19	27	10-10-2017	08:31:00	10-10-2017	21:15:00	31.77	Bucket changing work	12.73	SS3
KS19	28	14-10-2017	20:30:00	14-10-2017	21:20:00	95.25	Head lights problem	0.83	SS5
KS19	29	18-10-2017	13:00:00	18-10-2017	13:30:01	87.67	Ladders and Railings	0.5	SS4
KS19	30	23-10-2017	08:16:00	23-10-2017	11:50:00	114.77	Wear plates fixing	3.57	SS3
KS19	31	26-10-2017	13:30:00	26-10-2017	18:00:43	73.67	Hydraulic hose failed	4.51	SS7
KS19	32	27-10-2017	12:31:00	27-10-2017	17:55:55	18.50	Grease hose failed in arm Cylinder	5.42	SS1
KS19	33	28-10-2017	08:01:00	28-10-2017	10:35:00	14.08	Grease hose failed in arm Cylinder	2.57	SS2
KS19	34	30-10-2017	08:30:00	30-10-2017	15:01:00	45.92	Hydraulic hose failed	6.52	SS7
KS19	35	31-10-2017	15:00:00	31-10-2017	22:40:00	23.98	Bucket changing work	7.67	SS3
KS19	36	31-10-2017	23:40:00	01-11-2017	15:15:00	1.00	Bucket not opening	15.58	SS3
KS19	37	03-11-2017	21:30:00	03-11-2017	22:20:00	54.25	Initial problem (engine not starting)	0.83	SS5
KS19	38	04-11-2017	20:45:00	04-11-2017	21:00:00	22.42	Electrical breakdown	0.25	SS5
KS19	39	07-11-2017	16:45:00	07-11-2017	16:50:00	67.75	Ladder / railing damaged	0.08	SS4
KS19	40	10-11-2017	08:35:00	10-11-2017	11:00:00	63.75	Hydraulic hose failed	2.42	SS7
KS19	41	10-11-2017	14:00:00	10-11-2017	16:40:00	3.00	Electrical breakdown	2.67	SS5
KS19	42	11-11-2017	22:40:00	11-11-2017	23:30:15	30.00	Electrical breakdown	0.84	SS5
KS19	43	12-11-2017	12:15:00	12-11-2017	12:20:00	12.75	Ladders and Railings	0.08	SS4
KS19	44	12-11-2017	15:30:03	12-11-2017	16:45:46	3.17	A/C not working	1.26	SS5
KS19	45	14-11-2017	05:00:00	14-11-2017	05:20:00	36.24	Horn/buzzer not working	0.33	SS4
KS19	46	17-11-2017	14:00:00	17-11-2017	17:00:30	80.67	Electrical breakdown	3.01	SS5
KS19	47	18-11-2017	07:40:00	18-11-2017	07:45:00	14.66	Grease hose failed in arm cylinder	0.08	SS1
KS19	48	20-11-2017	15:35:06	20-11-2017	15:38:00	55.84	Problem occurred in power tong	0.05	SS9
KS19	49	22-11-2017	15:38:01	20-11-2017	22:30:00	48.00	Stick got cracks	6.87	SS2
KS19	50	22-11-2017	00:40:00	22-11-2017	00:45:00	26.17	Ladders and Railings	0.08	SS4
KS19	51	23-11-2017	14:45:00	23-11-2017	18:45:00	38.00	Hydraulic hose failed	4	SS7
KS19	52	24-11-2017	01:30:00	24-11-2017	01:35:00	6.75	Service operations slow	0.08	SS7
KS19	53	25-11-2017	00:10:00	25-11-2017	00:40:00	22.58	Horn problem	0.5	SS5

KS19	54	26-11-2017	16:00:00	26-11-2017	20:45:00	39.33	Exhaust gases leakage	4.75	SS6
KS19	55	27-11-2017	07:30:00	27-11-2017	15:01:00	10.75	Hydraulic hose failed	7.52	SS7
KS19	56	27-11-2017	17:30:00	30-11-2017	11:30:00	2.48	Hydraulic hose failed	66	SS7
KS19	57	04-12-2017	13:35:00	04-12-2017	13:55:00	98.08	Grease hose failed in boom cylinder	0.33	SS2
KS19	58	09-12-2017	03:00:00	10-12-2017	10:00:44	109.08	Hydraulic oil leakage	31.01	SS7
KS19	59	12-12-2017	18:30:00	12-12-2017	19:00:00	56.49	A / c not working	0.5	SS5
KS19	60	15-12-2017	23:30:00	16-12-2017	00:15:00	76.50	Ladder / railing damaged	0.75	SS4
KS19	61	17-12-2017	16:00:00	17-12-2017	16:30:00	39.75	Ladders and Railings	0.5	SS4
KS19	62	19-12-2017	16:00:00	19-12-2017	16:30:00	47.50	A / C not working	0.5	SS5
KS19	63	22-12-2017	19:20:00	22-12-2017	19:45:00	74.83	Service control valve lever broken	0.42	SS4
KS19	64	23-12-2017	17:30:00	23-12-2017	18:30:00	21.75	Hoist buttons / lever problem	1	SS4
KS19	65	25-12-2017	18:00:37	25-12-2017	22:00:55	47.51	Grease hose failed in arm Cylinder	4	SS1
KS19	66	27-12-2017	12:56:39	27-12-2017	16:02:46	38.93	Hydraulic oil level low	3.1	SS7
					MTBF of KS19	**91.06**	**MTTR of KS19**	**3.841**	
Systems	**No. of failures**	**Start Date**	**Start Time**	**End date**	**End Time**	**TBF, hrs**	**Reasons**	**TTR, hrs**	**Failure Codes**
KS20	1	04-04-2017	07:00:00	04-04-2017	19:00:00	0.00	Bucket changing work	12	SS3
KS20	2	13-04-2017	15:00:00	13-04-2017	18:15:00	212.00	Track chain pin came out	3.25	SS10
KS20	3	16-04-2017	23:30:00	17-04-2017	00:15:00	77.25	Grease hose failed in boom cylinder	0.75	SS2
KS20	4	17-04-2017	07:00:00	17-04-2017	08:20:00	6.75	Grease hose failed in arm cylinder	1.33	SS1
KS20	5	20-04-2017	18:50:00	21-04-2017	01:45:00	82.50	Hydraulic hose failed	6.92	SS7
KS20	6	22-04-2017	08:01:00	22-04-2017	10:20:00	30.27	Grease pump not working	2.32	SS7
KS20	7	24-04-2017	16:55:00	24-04-2017	18:50:00	54.58	Engine off in running	1.92	SS6
KS20	8	19-05-2017	12:00:51	19-05-2017	13:00:41	593.18	Hydraulic oil leakage	1	SS7
KS20	9	31-05-2017	08:30:00	31-05-2017	08:40:00	283.49	Cabin vibration	0.17	SS4
KS20	10	02-06-2017	09:01:00	02-06-2017	11:15:00	48.35	Track chain pin came out	2.23	SS10
KS20	11	03-06-2017	08:01:00	03-06-2017	09:00:00	20.77	Grease hose failed in boom cylinder	0.98	SS2
KS20	12	03-06-2017	09:45:00	03-06-2017	09:55:00	0.75	Grease hose failed in arm cylinder	0.17	SS1
KS20	13	03-06-2017	23:01:00	04-06-2017	17:00:00	13.10	Alternator belt cut/ missed	17.98	SS9
KS20	14	08-06-2017	09:05:56	08-06-2017	10:30:03	88.10	Hydraulic oil leakage	1.4	SS7
KS20	15	08-06-2017	18:25:00	08-06-2017	18:55:00	7.92	Horn/buzzer not working	0.5	SS4
KS20	16	27-06-2017	06:20:00	27-06-2017	11:00:00	443.42	Hydraulic hose failed	4.67	SS7

KS20	17	28-06-2017	23:30:00	28-06-2017	23:45:00	36.50	Ladder / railing damaged	0.25	SS4
KS20	18	03-07-2017	17:30:00	03-07-2017	18:00:00	113.75	Lighting problem	0.5	SS5
KS20	19	07-07-2017	17:40:00	07-07-2017	18:30:00	95.67	Dump valve problem	0.83	SS9
KS20	20	10-07-2017	04:30:00	10-07-2017	08:30:00	58.00	Service control valve lever broken	4	SS4
KS20	21	17-07-2017	09:00:00	17-07-2017	11:00:00	168.50	Bucket changing work	2	SS3
KS20	22	23-07-2017	01:00:00	23-07-2017	01:15:00	134.00	Grease container empty	0.25	SS7
KS20	23	31-07-2017	07:35:00	31-07-2017	07:40:00	198.33	Collision	0.08	SS9
KS20	24	01-08-2017	08:31:00	01-08-2017	17:00:48	24.85	Grease pump not working	8.5	SS7
KS20	25	11-08-2017	21:20:00	11-08-2017	21:35:00	244.32	Tooth point missed	0.25	SS10
KS20	26	12-08-2017	15:00:00	12-08-2017	18:00:00	17.42	A / C not working	3	SS5
KS20	27	14-08-2017	02:40:26	14-08-2017	04:45:47	32.67	Grease hose failed in arm cylinder	2.09	SS1
KS20	28	17-08-2017	17:30:00	17-08-2017	17:50:00	84.74	Bucket door cylinder failed	0.33	SS3
KS20	29	19-08-2017	18:00:00	19-08-2017	18:20:00	48.17	Hoist buttons / lever problem	0.33	SS4
KS20	30	24-08-2017	23:30:00	25-08-2017	01:30:00	125.17	Engine rpm not raising/lowering	2	SS6
KS20	31	25-08-2017	08:31:00	25-08-2017	09:20:00	7.02	Engine rpm not raising/lowering	0.82	SS6
KS20	32	26-08-2017	16:30:11	26-08-2017	18:20:13	31.17	Engine rpm not raising/lowering	1.83	SS6
KS20	33	27-08-2017	09:01:00	09-09-2017	09:45:00	14.68	Track pin missing/came out	312.73	SS10
KS20	34	09-09-2017	13:45:00	09-09-2017	14:20:00	4.00	Grease container empty	0.58	SS7
KS20	35	10-09-2017	07:00:00	16-09-2017	19:00:00	16.67	Bucket crack	156	SS3
KS20	36	19-09-2017	07:00:19	19-09-2017	08:30:09	60.01	Grease hose failed in arm cylinder	1.5	SS1
KS20	37	21-09-2017	12:00:05	22-09-2017	12:45:55	51.50	Hydraulic hose failed	24.76	SS7
KS20	38	27-09-2017	17:30:00	27-09-2017	17:45:00	124.73	Grease hose failed in boom cylinder	0.25	SS2
KS20	39	27-09-2017	23:20:48	28-09-2017	00:00:33	5.60	Engine rpm not raising/lowering	0.66	SS6
KS20	40	01-10-2017	21:13:45	02-10-2017	14:15:00	93.22	Hydraulic oil leakage	17.02	SS7
KS20	41	09-10-2017	20:30:00	09-10-2017	21:50:00	174.25	Head lights problem	1.33	SS5
KS20	42	10-10-2017	09:00:00	10-10-2017	09:05:00	11.17	Hose guard detached	0.08	SS9
KS20	43	10-10-2017	16:00:00	10-10-2017	17:00:00	6.92	Hydraulic oil level low	1	SS7
KS20	44	11-10-2017	14:40:00	12-10-2017	05:00:00	21.67	Tooth point adapter missing	14.33	SS3
KS20	45	16-10-2017	16:00:00	16-10-2017	16:40:00	107.00	Ladder / railing damaged	0.67	SS4
KS20	46	17-10-2017	16:00:00	17-10-2017	16:15:00	23.33	A / C not working	0.25	SS5
KS20	47	20-10-2017	08:15:01	20-10-2017	09:15:00	64.00	Engine rpm not raising/lowering	1	SS6
KS20	48	21-10-2017	17:30:00	21-10-2017	17:45:00	32.25	Hoist cylinder metallic pipes damaged	0.25	SS7

KS20	49	23-10-2017	07:15:00	23-10-2017	07:25:00	37.50	Bucket front guard damaged	0.17	SS3
KS20	50	23-10-2017	14:45:00	23-10-2017	16:45:22	7.33	Fire suppression system problem	2.01	SS4
KS20	51	25-10-2017	16:30:27	25-10-2017	16:45:36	47.75	Grease container empty	0.25	SS7
KS20	52	27-10-2017	08:01:00	27-10-2017	12:10:00	39.26	Foot step ladder damaged	4.15	SS4
KS20	53	02-11-2017	09:30:48	02-11-2017	18:10:00	141.35	Hydraulic oil leakage	8.65	SS6
KS20	54	11-11-2017	17:10:00	11-11-2017	18:00:00	215.00	Engine rpm not raising/lowering	0.83	SS6
KS20	55	14-11-2017	16:00:00	14-11-2017	16:05:00	70.00	Ladder / railing damaged	0.08	SS4
KS20	56	24-11-2017	00:30:00	24-11-2017	00:35:00	224.42	Grease container empty	0.08	SS7
KS20	57	29-11-2017	17:50:00	29-11-2017	19:15:00	137.25	Grease hose failed in boom cylinder	1.42	SS2
KS20	58	29-11-2017	19:50:00	29-11-2017	22:20:00	0.58	Grease hose failed in arm cylinder	2.5	SS1
KS20	59	30-11-2017	16:30:00	30-11-2017	16:50:00	18.17	A / C not working	0.33	SS5
KS20	60	03-12-2017	11:17:28	03-12-2017	11:20:00	66.46	Problem occured in power tong	0.04	SS9
KS20	61	03-12-2017	17:50:03	03-12-2017	18:55:00	6.50	Grease hose failed in arm cylinder	1.08	SS1
KS20	62	04-12-2017	01:50:00	04-12-2017	02:20:00	6.92	Horn/buzzer not working	0.5	SS4
KS20	63	05-12-2017	00:30:00	05-12-2017	01:00:00	22.17	Horn/buzzer not working	0.5	SS4
KS20	64	08-12-2017	08:31:00	08-12-2017	11:30:00	79.52	Bucket crack	2.98	SS3
KS20	65	13-12-2017	14:10:00	13-12-2017	20:00:00	122.67	Hydraulic oil leakage	5.83	SS7
KS20	66	17-12-2017	16:15:00	17-12-2017	16:25:00	92.25	Engine oil level low	0.17	SS6
KS20	67	19-12-2017	16:00:00	19-12-2017	16:50:00	47.58	Engine rpm not raising/lowering	0.83	SS6
KS20	68	24-12-2017	06:58:43	24-12-2017	10:20:00	110.15	Hydraulic oil leakage	3.35	SS7
KS20	69	24-12-2017	23:01:00	25-12-2017	03:45:00	12.68	Hydraulic oil leakage	4.73	SS7
KS20	70	31-12-2017	19:00:00	31-12-2017	19:30:00	159.25	Electrical breakdown	0.5	SS5
					MTBF of KS20	**83.69**	**MTTR of KS20**	**9.40**	
Systems	**No. of failures**	**Start Date**	**Start Time**	**End date**	**End Time**	**TBF, hrs**	**Reasons**	**TTR, hrs**	**Failure Codes**
BD21	1	03-04-2017	15:30:00	03-04-2017	17:15:00	0.00	Bucket hinge mtg holes worn out	1.75	DS8
BD21	2	05-04-2017	16:00:00	09-04-2017	08:30:00	46.75	Sound from front right planetary	88.5	DS2
BD21	3	09-04-2017	09:45:00	09-04-2017	22:59:31	1.25	Engine off in running	13.24	DS5
BD21	4	11-04-2017	00:30:58	11-04-2017	11:30:00	25.52	Engine oil pressure low	10.98	DS5
BD21	5	17-04-2017	01:30:00	17-04-2017	09:00:00	134.00	Transmission, convertor reverse gear not	7.5	DS10
BD21	6	18-04-2017	00:30:00	18-04-2017	12:00:00	15.50	Transmission, convertor gears not engaging	11.5	DS10
BD21	7	19-04-2017	05:30:00	19-04-2017	13:30:00	17.50	Steering cylinder oil leakage	8	DS7

BD21	8	28-04-2017	08:50:00	28-04-2017	16:30:39	211.33	Steering hard	7.68	DS7
BD21	9	04-05-2017	17:10:12	06-05-2017	09:00:00	144.66	Electrical breakdown	39.83	DS4
BD21	10	08-05-2017	00:10:00	08-05-2017	00:40:00	39.17	Transmission, convertor reverse gear not	0.5	DS10
BD21	11	17-05-2017	23:01:00	18-05-2017	08:35:14	238.35	Transmission, convertor gears not engaging	9.57	DS10
BD21	12	18-05-2017	12:32:15	18-05-2017	13:01:32	3.95	Transmission, convertor gears not engaging	0.49	DS10
BD21	13	25-05-2017	04:00:00	25-05-2017	11:30:00	158.97	Reverse gear not engaging	7.5	DS4
BD21	14	27-05-2017	03:00:49	27-05-2017	08:06:36	39.51	Electrical breakdown	5.1	DS4
BD21	15	29-05-2017	17:30:02	30-05-2017	08:15:14	57.39	Transmission, convertor reverse gear not	14.75	DS10
BD21	16	30-05-2017	17:40:00	30-05-2017	18:00:00	9.41	Electrical breakdown	0.33	DS4
BD21	17	30-05-2017	22:00:00	31-05-2017	09:45:57	4.00	Hoist problem in engine	11.77	DS5
BD21	18	25-06-2017	00:45:00	26-06-2017	13:52:42	590.98	Suspension weak r/r	37.13	DS6
BD21	19	27-06-2017	18:30:00	28-06-2017	12:12:24	28.62	Hydraulic oil leakage	17.71	DS5
BD21	20	29-06-2017	22:15:00	30-06-2017	07:15:21	34.04	Initial problem (engine not starting)	9.01	DS5
BD21	21	01-07-2017	21:30:00	02-07-2017	10:45:48	38.24	Initial problem (engine not starting)	13.26	DS5
BD21	22	05-07-2017	19:40:00	06-07-2017	08:30:18	80.90	Transmission, convertor reverse gear not	12.84	DS10
BD21	23	07-07-2017	02:30:42	07-07-2017	13:24:17	18.01	Initial problem (engine not starting)	10.89	DS5
BD21	24	09-07-2017	07:30:00	09-07-2017	08:50:29	42.10	Transmission, convertor gears not engaging	1.34	DS10
BD21	25	09-07-2017	17:15:57	09-07-2017	20:35:22	8.42	Initial problem (engine not starting)	3.32	DS5
BD21	26	10-07-2017	01:15:00	10-07-2017	09:46:01	4.66	Transmission, convertor gears not upshift	8.52	DS10
BD21	27	10-07-2017	15:00:44	11-07-2017	15:00:30	5.25	Transmission, convertor gears not engaging	24	DS10
BD21	28	12-07-2017	05:30:00	12-07-2017	11:30:00	14.49	Transmission, convertor gears not upshift	6	DS10
BD21	29	13-07-2017	02:15:00	13-07-2017	15:30:28	14.75	Gears not engaging	13.26	DS4
BD21	30	14-07-2017	07:30:00	14-07-2017	08:10:00	15.99	Horn/buzzer not working	0.67	DS8
BD21	31	22-07-2017	08:35:21	22-07-2017	09:02:20	192.42	Suspension hammering	0.45	DS6
BD21	32	22-07-2017	16:15:00	22-07-2017	18:45:00	7.21	Transmission, convertor transmission oil	2.5	DS10
BD21	33	24-07-2017	12:20:00	24-07-2017	22:30:00	41.58	Hydraulic hose failed	10.17	DS6
BD21	34	31-07-2017	13:50:00	31-07-2017	15:31:35	159.33	Transmission, convertor transmission oil	1.69	DS10
BD21	35	05-08-2017	02:30:00	06-08-2017	10:35:39	106.97	Transmission, convertor propel shaft broken	32.09	DS10
BD21	36	19-08-2017	14:30:00	20-08-2017	14:50:00	315.91	Transmission, convertor propel shaft broken	24.33	DS10
BD21	37	23-08-2017	02:15:00	23-08-2017	12:30:19	59.42	Hydraulic hose failed	10.26	DS6
BD21	38	26-08-2017	18:45:47	26-08-2017	20:35:39	78.26	Initial problem (engine not starting)	1.83	DS5
BD21	39	28-08-2017	23:30:00	29-08-2017	00:10:00	50.91	Reverse light not glowing	0.67	DS4

BD21	40	02-09-2017	10:30:00	03-09-2017	07:13:22	106.33	Alternator not working	20.72	DS4
BD21	41	05-09-2017	12:30:00	06-09-2017	07:00:37	53.28	A / C not working	18.51	DS4
BD21	42	07-09-2017	10:10:00	07-09-2017	15:00:11	27.16	A / C not working	4.84	DS4
BD21	43	12-09-2017	20:30:55	12-09-2017	20:55:32	125.51	Tire replacement	0.41	DS9
BD21	44	15-09-2017	02:45:00	16-09-2017	07:00:00	53.82	Hydraulic hose failed	28.25	DS6
BD21	45	16-09-2017	16:00:00	17-09-2017	08:00:00	9.00	Electrical breakdown	16	DS4
BD21	46	17-09-2017	15:30:00	17-09-2017	20:00:00	7.50	Universal joint replacement	4.5	DS2
BD21	47	18-09-2017	03:45:00	18-09-2017	06:30:00	7.75	Initial problem (engine not starting)	2.75	DS4
BD21	48	19-09-2017	22:20:00	21-09-2017	16:35:00	39.83	Transmission, convertor propel shaft bro	42.25	DS10
BD21	49	28-09-2017	00:20:25	28-09-2017	02:00:09	151.76	Ladders, railings	1.66	DS8
BD21	50	03-10-2017	14:20:00	04-10-2017	20:00:00	132.33	Transmission, convertor transmission oil	29.67	DS10
BD21	51	05-10-2017	08:20:00	05-10-2017	12:52:36	12.33	Steering hard	4.54	DS7
BD21	52	07-10-2017	13:40:00	07-10-2017	15:00:32	48.79	Ladders, railings	1.34	DS8
BD21	53	08-10-2017	11:30:00	08-10-2017	12:06:42	20.49	A / C not working	0.61	SS4
BD21	54	09-10-2017	16:40:00	09-10-2017	22:00:00	28.56	Parking brake not functioning properly	5.33	DS1
BD21	55	16-10-2017	09:31:00	16-10-2017	22:50:00	155.52	Steering cylinder ball stud problem	13.32	DS7
BD21	56	18-10-2017	12:30:00	18-10-2017	17:38:00	37.67	Initial problem (engine not starting)	5.13	DS4
BD21	57	19-10-2017	09:40:00	19-10-2017	11:40:00	16.03	Initial problem (engine not starting)	2	DS4
BD21	58	19-10-2017	13:10:00	19-10-2017	18:45:00	1.50	Engine off in running	5.58	DS5
BD21	59	20-10-2017	10:00:00	25-10-2017	15:00:00	15.25	Transmission, convertor propel shaft bro	125	DS10
BD21	60	25-10-2017	15:01:00	30-10-2017	10:12:01	0.02	Universal joint broken	115.18	DS2
BD21	61	30-10-2017	16:00:00	30-10-2017	19:30:00	5.80	Brakes weak	3.5	DS1
BD21	62	31-10-2017	23:30:00	31-10-2017	23:50:00	28.00	Electrical breakdown	0.33	DS4
BD21	63	01-11-2017	19:45:00	01-11-2017	20:45:00	19.92	Parking brake not functioning properly	1	DS1
BD21	64	03-11-2017	13:50:00	05-11-2017	07:00:28	41.08	Hydraulic hose failed	41.17	DS6
BD21	65	05-11-2017	16:45:00	05-11-2017	22:00:00	9.74	Brakes weak	5.25	DS1
BD21	66	08-11-2017	06:00:45	08-11-2017	14:20:00	56.01	Suspension weak	8.32	DS6
BD21	67	10-11-2017	08:10:00	10-11-2017	08:20:00	41.83	Reverse alarm not working	0.17	DS4
BD21	68	12-11-2017	00:05:33	12-11-2017	17:15:44	39.76	Water boiling	17.17	DS5
BD21	69	13-11-2017	16:50:22	13-11-2017	22:47:51	23.58	Electrical breakdown	5.96	DS4
BD21	70	14-11-2017	16:30:00	14-11-2017	23:50:00	17.70	Electrical breakdown	7.33	DS4
BD21	71	15-11-2017	01:00:00	15-11-2017	09:51:48	1.17	Brakes weak	8.86	DS1

BD21	72	17-11-2017	18:00:00	17-11-2017	23:55:00	56.14	Suspension hammering	5.92	DS6
BD21	73	19-11-2017	17:00:00	19-11-2017	19:00:00	41.08	Suspension hammering	2	DS6
BD21	74	21-11-2017	12:00:00	21-11-2017	19:50:00	41.00	Abnormal sound from engine	7.83	DS5
BD21	75	24-11-2017	10:15:39	24-11-2017	13:53:06	62.43	Suspension hammering	3.62	DS6
BD21	76	24-11-2017	15:00:00	24-11-2017	17:15:00	1.12	Suspension hammering	2.25	DS6
BD21	77	24-11-2017	17:30:00	25-11-2017	12:50:20	0.25	Transmission, convertor gears not upshift	19.34	DS10
BD21	78	25-11-2017	15:00:00	26-11-2017	15:20:32	2.16	Transmission, convertor gears not upshift	24.34	DS10
BD21	79	27-11-2017	01:00:14	28-11-2017	23:56:43	9.66	Initial problem (engine not starting)	46.94	DS5
BD21	80	29-11-2017	11:30:00	30-11-2017	13:50:00	11.55	Transmission, convertor gears not engaging	26.33	DS10
BD21	81	30-11-2017	16:00:00	30-11-2017	16:50:00	2.17	Tire replacement	0.83	DS9
BD21	82	30-11-2017	23:50:00	01-12-2017	15:30:00	7.00	Transmission, convertor reverse gear not	15.67	DS10
BD21	83	03-12-2017	09:00:00	04-12-2017	20:45:58	41.50	Electrical breakdown	35.77	DS4
BD21	84	07-12-2017	10:30:00	07-12-2017	12:20:00	61.73	Initial problem (engine not starting)	1.83	DS5
BD21	85	08-12-2017	07:01:00	10-12-2017	10:00:00	18.68	Parking brake not functioning properly	50.98	DS1
BD21	86	11-12-2017	17:00:00	12-12-2017	00:15:00	31.00	Suspension hammering	7.25	DS6
BD21	87	12-12-2017	18:00:00	15-12-2017	01:11:04	17.75	Parking brake not functioning properly	55.18	DS1
BD21	88	15-12-2017	15:00:00	15-12-2017	16:45:00	13.82	Parking brake not functioning properly	1.75	DS1
BD21	89	16-12-2017	23:30:00	17-12-2017	00:15:00	30.75	Electrical breakdown	0.75	DS4
BD21	90	20-12-2017	02:00:00	20-12-2017	18:30:00	73.75	Initial problem (engine not starting)	16.5	DS5
BD21	91	25-12-2017	23:30:00	26-12-2017	15:57:03	125.00	Transmission, convertor gears not engaging	16.45	DS10
MTBF of BD21						**55.38**	**MTTR of BD21**	**15.045**	
Systems	**No. of failures**	**Start Date**	**Start Time**	**End date**	**End Time**	**TBF, hrs**	**Reasons**	**TTR, hrs**	**Failure Codes**
BD22	1	04-04-2017	17:20:00	05-04-2017	18:30:00	0.00	Gears not engaging	25.17	DS3
BD22	2	07-04-2017	20:30:00	07-04-2017	21:45:00	50.00	Transmission, convertor gears not engaging	1.25	DS10
BD22	3	08-04-2017	16:10:00	08-04-2017	18:00:00	18.42	Transmission, convertor gears not upshift	1.83	DS10
BD22	4	10-04-2017	11:55:00	10-04-2017	15:00:00	41.92	Transmission, convertor gears not engaging	3.08	DS10
BD22	5	11-04-2017	07:00:00	11-04-2017	13:00:00	16.00	Gears not engaging	6	DS3
BD22	6	03-05-2017	18:00:00	03-05-2017	23:30:46	533.00	Parking brake not functioning properly	5.51	DS1
BD22	7	04-05-2017	02:23:20	04-05-2017	05:51:21	2.88	Transmission, convertor gears not engaging	3.47	DS10
BD22	8	04-05-2017	11:30:00	04-05-2017	17:30:26	5.64	Engine oil leakage	6.01	DS5
BD22	9	06-05-2017	00:10:37	06-05-2017	04:00:30	30.67	Initial problem (engine not starting)	3.83	DS5

BD22	10	09-05-2017	23:30:40	10-05-2017	10:00:58	91.50	Transmission, convertor gears not engaging	10.51	DS10
BD22	11	13-05-2017	23:00:00	14-05-2017	01:00:33	84.98	Transmission, convertor reverse gear not	2.01	DS10
BD22	12	15-05-2017	12:30:00	15-05-2017	17:21:15	35.49	Electrical breakdown	4.85	DS4
BD22	13	16-05-2017	05:22:00	18-05-2017	13:01:55	12.01	Ladders and railings damage	55.67	DS8
BD22	14	18-05-2017	18:40:00	18-05-2017	19:20:00	5.63	Transmission, convertor gears not upshift	0.67	DS10
BD22	15	19-05-2017	12:15:03	20-05-2017	17:02:23	16.92	Transmission, convertor gears not upshift	28.79	DS10
BD22	16	22-05-2017	10:00:00	22-05-2017	19:00:00	40.96	Transmission, convertor gears not engaging	9	DS10
BD22	17	24-05-2017	00:07:08	24-05-2017	01:07:50	29.12	Initial problem (engine not starting) due to power	1.01	DS4
BD22	18	24-05-2017	10:00:00	24-05-2017	12:00:02	8.87	Lock damaged	2	DS8
BD22	19	26-05-2017	09:15:00	27-05-2017	19:30:00	45.25	Hydraulic oil leakage	34.25	DS6
BD22	20	30-05-2017	23:30:00	31-05-2017	07:00:00	76.00	A / C not working door	7.5	DS4
BD22	21	01-06-2017	22:30:57	02-06-2017	08:30:28	39.52	Transmission, convertor reverse gear not	9.99	DS10
BD22	22	02-06-2017	22:40:00	02-06-2017	12:55:00	14.16	Reverse gear not engaging	14.25	DS3
BD22	23	05-06-2017	00:50:00	05-06-2017	18:30:00	59.92	Universal joint broken	17.67	DS2
BD22	24	09-06-2017	15:00:00	12-06-2017	03:00:00	92.50	Hydraulic oil level low in steering	60	DS7
BD22	25	17-06-2017	15:01:00	18-06-2017	12:30:00	132.02	Tyre punctured and O- ring replacement	21.48	DS9
BD22	26	23-06-2017	14:00:00	25-06-2017	00:15:00	121.50	Transmission, convertor transmission oil	34.25	DS10
BD22	27	28-06-2017	07:30:57	28-06-2017	13:15:50	79.27	Transmission, convertor gears not upshift	5.75	DS10
BD22	28	28-06-2017	20:00:00	29-06-2017	12:50:29	6.74	Transmission, convertor rear drive line	16.84	DS10
BD22	29	20-07-2017	04:30:00	20-07-2017	09:00:24	495.66	Transmission, convertor gears not engaging	4.51	DS10
BD22	30	03-08-2017	15:30:17	04-08-2017	11:23:10	342.50	Brake oil hose failed in breaking system	19.88	DS1
BD22	31	06-08-2017	00:35:00	06-08-2017	01:00:00	37.20	Head lights problem	0.42	DS4
BD22	32	06-08-2017	01:15:00	06-08-2017	02:15:01	0.25	Transmission, convertor propel shaft bro	1.000277778	DS10
BD22	33	06-08-2017	11:30:30	06-08-2017	11:50:32	9.26	Hydraulic oil leakage in left suspension system	0.33	DS6
BD22	34	06-08-2017	18:30:00	06-08-2017	22:00:00	6.66	Cabin door lock problem	3.5	DS8
BD22	35	07-08-2017	15:00:00	07-08-2017	17:00:00	17.00	Hydraulic oil leakage lift cylinder	2	DS6
BD22	36	07-08-2017	23:30:00	08-08-2017	00:05:00	6.50	Electrical breakdown	0.58	DS4
BD22	37	08-08-2017	11:00:00	08-08-2017	15:00:01	10.92	Tyre got damaged	4	DS9
BD22	38	11-08-2017	18:00:00	12-08-2017	17:00:00	75.00	Water leak from water pump seal	23	DS6
BD22	39	17-08-2017	04:15:59	17-08-2017	04:25:53	107.27	Electrical breakdown	0.17	DS4
BD22	40	23-08-2017	01:30:00	23-08-2017	02:10:00	141.07	Head lights problem	0.67	DS4

BD22	41	24-08-2017	12:00:00	24-08-2017	12:20:00	33.83	Electrical breakdown	0.33	DS4
BD22	42	05-09-2017	23:30:15	06-09-2017	01:00:08	299.17	Steering hard	1.5	DS7
BD22	43	06-09-2017	05:00:45	06-09-2017	06:50:42	4.01	Electrical breakdown	1.83	DS4
BD22	44	06-09-2017	19:30:00	07-09-2017	11:30:00	12.66	Head lights problem	16	DS4
BD22	45	09-09-2017	22:55:33	10-09-2017	09:00:00	59.43	Electrical breakdown	10.07	DS4
BD22	46	12-09-2017	18:40:35	12-09-2017	19:05:19	57.68	Head lights problem	0.41	DS4
BD22	47	13-09-2017	07:30:00	13-09-2017	13:50:00	12.41	Initial problem (engine not starting)	6.33	DS5
BD22	48	19-09-2017	08:00:56	19-09-2017	08:10:45	138.18	Hydraulic oil leakage suspension system	0.16	DS6
BD22	49	21-09-2017	07:30:48	21-09-2017	15:45:00	47.33	Tyre got damaged	8.24	DS9
BD22	50	22-09-2017	09:50:30	26-09-2017	00:20:17	18.09	Electrical breakdown	86.5	DS4
BD22	51	26-09-2017	08:15:00	27-09-2017	18:00:00	7.91	A / c not working	33.75	DS4
BD22	52	29-09-2017	13:10:00	29-09-2017	23:50:00	43.17	Battery weak starting problem	10.67	DS4
BD22	53	02-10-2017	17:00:37	02-10-2017	17:50:54	65.18	Transmission, convertor gears not engagi	0.84	DS10
BD22	54	07-10-2017	12:01:00	07-10-2017	15:29:08	114.17	Hydraulic oil leakage at engine	3.47	DS5
BD22	55	07-10-2017	17:30:00	07-10-2017	18:20:00	2.01	Final drive problem	0.83	DS2
BD22	56	07-10-2017	21:30:15	07-10-2017	22:45:14	3.17	No side mirror	1.25	DS8
BD22	57	17-10-2017	23:30:15	18-10-2017	17:00:00	240.75	No water in radiator	17.5	DS5
BD22	58	18-10-2017	23:00:50	19-10-2017	08:15:00	6.01	Tyre air inflation less	9.24	DS9
BD22	59	20-10-2017	15:30:00	21-10-2017	11:45:00	31.25	No water in radiator	20.25	DS5
BD22	60	22-10-2017	18:30:00	22-10-2017	21:55:00	30.75	Gears not engaging	3.42	DS3
BD22	61	22-10-2017	23:30:00	23-10-2017	08:16:36	1.58	Alternator belt cut/ missed	8.78	DS8
BD22	62	23-10-2017	15:00:14	23-10-2017	23:45:00	6.73	Chasse welding	8.75	DS8
BD22	63	24-10-2017	07:30:00	24-10-2017	16:31:22	7.75	Ladders and Railings damage	9.02	DS8
BD22	64	25-10-2017	09:50:00	26-10-2017	00:00:18	17.31	Initial problem (engine not starting)	14.17	DS4
BD22	65	29-10-2017	04:00:00	31-10-2017	07:00:53	76.00	Transmission, convertor gears not engaging	51.01	DS10
BD22	66	01-11-2017	06:15:00	02-11-2017	16:42:21	23.24	Engine rpm not raising/lowering	34.46	DS5
BD22	67	03-11-2017	12:00:19	04-11-2017	13:41:12	19.30	Hydraulic oil leakage in left suspension system	25.68	DS6
BD22	68	04-11-2017	21:15:00	08-11-2017	14:20:00	7.56	Transmission, convertor propel shaft bro	89.08	DS10
BD22	69	08-11-2017	17:45:00	09-11-2017	00:00:30	3.42	Tyre O-ring failed	6.26	DS9
BD22	70	12-11-2017	01:30:30	12-11-2017	10:00:00	73.50	Initial problem (engine not starting)	8.49	DS5
BD22	71	15-11-2017	05:00:00	17-11-2017	17:00:27	67.00	Transmission, convertor propel shaft bro	60.01	DS10

BD22	72	17-11-2017	18:00:00	17-11-2017	19:00:00	0.99	Engine rpm not raising/lowering	1	DS5
BD22	73	19-11-2017	08:50:00	23-11-2017	09:17:31	37.83	Gears not engaging	96.46	DS3
BD22	74	23-11-2017	11:00:35	23-11-2017	14:00:16	1.72	Initial problem (engine not starting)	2.99	DS5
BD22	75	25-11-2017	10:30:00	25-11-2017	12:30:41	44.50	Initial problem (engine not starting)	2.01	DS5
BD22	76	28-11-2017	07:01:00	28-11-2017	23:50:56	66.51	Transmission, convertor propel shaft bro	16.83	DS10
BD22	77	02-12-2017	18:00:00	02-12-2017	23:52:25	90.15	Electrical breakdown	5.87	DS4
BD22	78	03-12-2017	04:00:44	03-12-2017	12:57:33	4.14	Initial problem (engine not starting)	8.95	DS5
BD22	79	03-12-2017	17:55:28	05-12-2017	08:20:02	4.97	Engine off in running	38.41	DS5
BD22	80	05-12-2017	18:35:50	05-12-2017	23:55:00	10.26	Transmission, convertor gears not engaging	5.32	DS10
BD22	81	06-12-2017	01:00:00	06-12-2017	17:10:22	1.08	Initial problem (engine not starting)	16.17	DS5
BD22	82	06-12-2017	18:15:06	06-12-2017	23:01:00	1.08	Transmission, convertor gears not upshift	4.76	DS10
BD22	83	07-12-2017	01:00:00	07-12-2017	11:30:00	1.98	Electrical breakdown	10.5	DS4
BD22	84	07-12-2017	13:30:00	07-12-2017	23:55:00	2.00	Engine rpm not raising/lowering	10.42	DS5
BD22	85	08-12-2017	08:00:00	08-12-2017	10:12:59	8.08	Differential, final drive, wheels	2.22	DS2
BD22	86	11-12-2017	07:30:00	12-12-2017	00:00:00	69.28	Initial problem (engine not starting)	40.5	DS5
BD22	87	16-12-2017	10:00:42	17-12-2017	00:08:56	82.01	Initial problem (engine not starting)	14.14	DS5
BD22	88	17-12-2017	08:45:00	17-12-2017	23:55:00	8.60	Transmission, convertor propel shaft bro	15.17	DS10
BD22	89	19-12-2017	09:45:00	19-12-2017	10:15:00	33.83	Initial problem (engine not starting)	0.5	DS5
BD22	90	19-12-2017	13:20:00	19-12-2017	23:55:47	3.08	Transmission, convertor transmission oil	10.6	DS10
BD22	91	20-12-2017	17:30:00	21-12-2017	01:00:00	17.57	Transmission, convertor transmission oil	7.5	DS10
BD22	92	21-12-2017	09:30:00	22-12-2017	02:15:19	8.50	Tyre O-ring failed	16.76	DS9
BD22	93	23-12-2017	15:40:00	23-12-2017	19:00:00	37.41	Transmission, convertor transmission oil	3.33	DS10
BD22	94	24-12-2017	19:00:00	24-12-2017	23:01:00	24.00	Suspension hammering	4.02	DS6
BD22	95	24-12-2017	23:45:00	25-12-2017	10:10:00	0.73	Fire suppression system problem	10.42	DS8
BD22	96	25-12-2017	17:15:00	25-12-2017	23:55:00	7.08	Transmission, convertor transmission oil	6.67	DS10
BD22	97	27-12-2017	03:45:00	31-12-2017	17:00:00	27.83	Transmission, convertor propel shaft bro	109.25	DS10
					MTBF of BD22	**52.23**	**MTTR of BD22**	**15.070**	
Systems	**No. of failures**	**Start Date**	**Start Time**	**End date**	**End Time**	**TBF, hrs**	**Reasons**	**TTR, hrs**	**Failure Codes**
BD23	1	03-04-2017	07:30:35	06-04-2017	16:30:00	0.00	Hydraulic oil leakage in suspension system	80.99	DS6
BD23	2	12-04-2017	16:30:00	12-04-2017	17:00:00	144.00	Electrical breakdown	0.5	DS4
BD23	3	20-04-2017	06:30:00	20-04-2017	13:50:00	181.50	Engine not getting off	7.33	DS5

BD23	4	21-04-2017	10:00:00	21-04-2017	10:20:00	20.17	Electrical breakdown	0.33	DS4
BD23	5	22-04-2017	02:30:00	23-04-2017	06:30:00	16.17	Hydraulic oil leakage in suspension system	28	DS6
BD23	6	24-04-2017	10:30:54	24-04-2017	12:30:05	28.02	Electrical breakdown	1.99	DS4
BD23	7	26-04-2017	17:00:00	26-04-2017	17:05:00	52.50	Initial problem (engine not starting)	0.08	DS5
BD23	8	04-05-2017	11:30:00	04-05-2017	14:00:00	186.42	Initial problem (engine not starting)	2.5	DS5
BD23	9	09-05-2017	07:30:00	09-05-2017	08:00:00	113.50	Brakes not releasing	0.5	DS1
BD23	10	17-05-2017	11:30:00	18-05-2017	08:26:51	195.50	Silencer red hot	20.95	DS5
BD23	11	19-05-2017	22:30:00	20-05-2017	07:30:08	38.05	Electrical breakdown	9	DS4
BD23	12	24-05-2017	10:00:00	24-05-2017	12:00:47	98.50	Initial problem (engine not starting)	2.01	DS5
BD23	13	26-05-2017	12:00:00	26-05-2017	16:00:15	47.99	Chassis breakage	4	DS8
BD23	14	29-05-2017	17:00:51	30-05-2017	00:15:00	73.01	Initial problem (engine not starting)	7.24	DS5
BD23	15	30-05-2017	17:20:00	30-05-2017	23:30:00	17.08	Gears not engaging	6.17	DS3
BD23	16	01-06-2017	17:55:09	02-06-2017	00:30:00	42.42	Initial problem (engine not starting)	6.58	DS5
BD23	17	07-06-2017	08:30:00	07-06-2017	13:30:09	128.00	Engine coolant leaking	5	DS5
BD23	18	18-06-2017	10:10:00	18-06-2017	10:30:00	260.66	Engine rpm not raising/lowering	0.33	DS5
BD23	19	24-06-2017	05:00:09	24-06-2017	15:30:21	138.50	Engine oil pressure low	10.5	DS5
BD23	20	05-07-2017	19:40:00	06-07-2017	08:00:00	268.16	Initial problem (engine not starting)	12.33	DS5
BD23	21	09-07-2017	23:00:00	10-07-2017	10:00:15	87.00	Pivot pin replacement	11	DS2
BD23	22	22-07-2017	17:45:00	23-07-2017	13:45:00	295.75	Tyre punctured	20	DS9
BD23	23	30-07-2017	15:30:33	30-07-2017	17:00:13	169.76	Electrical breakdown	1.49	DS4
BD23	24	04-08-2017	13:00:00	06-08-2017	07:00:00	116.00	Tyre O-ring failed	42	DS9
BD23	25	13-08-2017	16:30:00	13-08-2017	19:00:00	177.50	Wheel bolts loose	2.5	DS9
BD23	26	17-08-2017	01:30:51	17-08-2017	01:40:49	78.51	Cabin fan not working	0.17	DS4
BD23	27	27-08-2017	23:30:00	27-08-2017	23:50:00	261.82	Electrical breakdown	0.33	DS4
BD23	28	01-09-2017	00:30:00	01-09-2017	11:30:02	96.67	Transmission, convertor gears not engaging	11	DS10
BD23	29	04-09-2017	02:10:29	04-09-2017	02:25:06	62.67	Transmission, convertor gears not engaging	0.24	DS10
BD23	30	05-09-2017	01:20:01	05-09-2017	01:30:15	22.92	Electrical breakdown	0.17	DS4
BD23	31	05-09-2017	09:30:00	05-09-2017	13:31:59	8.00	Initial problem (engine not starting)	4.03	DS5
BD23	32	05-09-2017	15:00:00	06-09-2017	09:15:03	1.47	Electrical breakdown	18.25	DS4
BD23	33	10-09-2017	23:00:00	11-09-2017	01:30:00	109.75	Hydraulic hose failed at lifting cylinder	2.5	DS6
BD23	34	14-09-2017	16:20:43	14-09-2017	16:30:35	86.85	Foot step ladder damaged	0.16	DS8
BD23	35	19-09-2017	08:30:17	19-09-2017	12:00:05	112.00	Electrical breakdown	3.5	DS4

BD23	36	19-09-2017	23:30:00	20-09-2017	16:15:00	11.50	Electrical breakdown	16.75	DS4
BD23	37	24-09-2017	21:00:00	26-09-2017	00:20:55	100.75	No water in radiator and Engine not working	27.35	DS5
BD23	38	27-09-2017	07:14:11	27-09-2017	22:50:00	30.89	Transmission, convertor gears not engaging	15.6	DS10
BD23	39	28-09-2017	04:10:06	29-09-2017	23:40:00	5.34	Transmission, convertor transmission oil	43.5	DS10
BD23	40	01-10-2017	15:30:25	02-10-2017	12:31:14	39.84	Electrical breakdown	21.01	DS4
BD23	41	02-10-2017	19:40:20	02-10-2017	23:30:00	7.15	Transmission, convertor reverse gear not	3.83	DS10
BD23	42	03-10-2017	03:35:00	03-10-2017	09:15:00	4.08	Gears not engaging	5.67	DS3
BD23	43	03-10-2017	10:30:00	03-10-2017	14:38:44	1.25	Transmission, convertor gears not engaging	4.15	DS10
BD23	44	03-10-2017	17:00:10	03-10-2017	21:50:00	2.36	Engine guard problem	4.83	DS5
BD23	45	04-10-2017	00:50:00	04-10-2017	20:00:00	3.00	Transmission, convertor gears not engaging	19.17	DS10
BD23	46	05-10-2017	00:30:00	07-10-2017	15:00:10	4.50	Transmission, convertor gears not upshift	62.5	DS10
BD23	47	07-10-2017	16:00:09	23-10-2017	14:17:12	1.00	Transmission, convertor gears not engaging	382.28	DS10
BD23	48	25-10-2017	05:30:00	26-10-2017	00:00:54	39.21	Electrical breakdown	18.52	DS4
BD23	49	26-10-2017	19:25:03	26-10-2017	20:00:12	19.40	Engine rpm not raising/lowering	0.59	DS5
BD23	50	29-10-2017	16:30:00	29-10-2017	17:00:00	68.50	Brakes not releasing	0.5	DS1
BD23	51	30-10-2017	08:15:00	30-10-2017	16:15:00	15.25	Brakes not releasing	8	DS1
BD23	52	31-10-2017	01:20:00	31-10-2017	01:50:00	9.08	Gears not engaging	0.5	DS4
BD23	53	31-10-2017	21:00:00	31-10-2017	22:30:00	19.17	Brakes not releasing	1.5	DS1
BD23	54	02-11-2017	14:00:59	02-11-2017	19:00:00	39.52	A / C not working	4.98	DS4
BD23	55	03-11-2017	16:30:00	04-11-2017	07:00:13	21.50	Brakes not releasing	14.5	DS1
BD23	56	04-11-2017	10:00:55	07-11-2017	12:22:11	3.01	Hydraulic oil leakage	74.35	DS6
BD23	57	08-11-2017	16:30:00	08-11-2017	17:30:00	28.13	Brakes not releasing	1	DS1
BD23	58	08-11-2017	18:15:00	08-11-2017	22:40:00	0.75	Brakes not releasing	4.42	DS1
BD23	59	09-11-2017	00:25:31	09-11-2017	19:00:00	1.76	Transmission, convertor gears not engaging	18.57	DS10
BD23	60	12-11-2017	01:45:27	12-11-2017	18:40:19	54.76	Engine rpm not raising/lowering	16.91	DS5
BD23	61	13-11-2017	18:30:26	13-11-2017	22:48:48	23.84	Brake boosters jam front	4.31	DS1
BD23	62	14-11-2017	01:00:00	03-12-2017	13:01:49	2.19	Transmission, convertor gears not engaging	468.03	DS10
BD23	63	04-12-2017	15:30:26	04-12-2017	19:30:16	26.48	Boulder got jammed between rear tyres	4	DS2
BD23	64	04-12-2017	21:20:30	04-12-2017	21:55:24	1.84	Brake boosters jam front	0.58	DS1
BD23	65	06-12-2017	00:15:00	06-12-2017	17:35:18	26.33	Transmission, convertor gears not upshift	17.34	DS10
BD23	66	08-12-2017	17:50:00	09-12-2017	00:15:00	48.25	Initial problem (engine not starting)	6.42	DS5
BD23	67	10-12-2017	23:30:00	11-12-2017	00:20:00	47.25	No water in radiator	0.83	DS5

BD23	68	15-12-2017	11:30:59	15-12-2017	20:00:00	107.18	Transmission, convertor transmission oil	8.48	DS10
BD23	69	15-12-2017	23:30:00	16-12-2017	00:10:00	3.50	Gears not engaging	0.67	DS4
BD23	70	16-12-2017	02:00:00	16-12-2017	02:40:00	1.83	Gears not engaging	0.67	DS4
BD23	71	17-12-2017	15:30:00	17-12-2017	19:00:00	36.83	No water in radiator	3.5	DS5
BD23	72	17-12-2017	20:30:00	18-12-2017	12:25:00	1.50	Initial problem (engine not starting)	15.92	DS4
BD23	73	18-12-2017	16:00:00	19-12-2017	07:00:00	3.58	Electrical breakdown	15	DS4
BD23	74	22-12-2017	07:30:00	23-12-2017	00:15:56	72.50	Transmission, convertor gears not upshift	16.77	DS10
BD23	75	24-12-2017	14:00:00	24-12-2017	14:30:00	37.73	Electrical breakdown	0.5	DS4
BD23	76	25-12-2017	06:00:00	25-12-2017	07:01:23	15.50	Hydraulic oil leakage	1.02	DS6
					MTBF of BD23	**62.17**	**MTTR of BD23**	**21.825**	
Systems	**No. of failures**	**Start Date**	**Start Time**	**End date**	**End Time**	**TBF, hrs**	**Reasons**	**TTR, hrs**	**Failure Codes**
KD24	1	13-04-2017	15:00:00	13-04-2017	20:35:00	0.00	Wheel bolts loose	5.58	SS9
KD24	2	15-04-2017	07:30:00	15-04-2017	12:00:00	34.92	Wheel bolts loose	4.5	SS9
KD24	3	26-04-2017	17:30:00	26-04-2017	18:00:00	269.50	Rear view mirror broken	0.5	SS8
KD24	4	02-05-2017	10:00:00	02-05-2017	12:30:00	136.00	Cabin door glass problem	2.5	SS8
KD24	5	09-05-2017	18:00:00	09-05-2017	18:30:00	173.50	Hoist cylinder hose failure	0.5	SS6
KD24	6	12-05-2017	23:30:00	13-05-2017	00:15:00	77.00	Lighting problem	0.75	DS4
KD24	7	15-05-2017	07:00:00	15-05-2017	08:00:00	54.75	Tyre air inflation less	1	SS9
KD24	8	20-05-2017	18:40:00	20-05-2017	19:15:00	130.67	Parking brake not functioning properly	0.58	DS1
KD24	9	20-05-2017	23:30:00	21-05-2017	17:00:00	4.25	Transmission, convertor gears not upshift	17.5	SS10
KD24	10	25-05-2017	23:30:00	26-05-2017	02:00:00	102.50	Head lights problem	2.5	DS4
KD24	11	28-05-2017	20:40:09	31-05-2017	12:50:00	66.67	Parking brake not functioning properly	64.16	DS1
KD24	12	03-06-2017	03:30:00	03-06-2017	04:10:00	62.67	Reverse light not glowing	0.67	DS4
KD24	13	06-06-2017	07:00:00	06-06-2017	08:00:00	74.83	Tyre air inflation less	1	SS9
KD24	14	24-06-2017	23:45:00	25-06-2017	00:30:00	447.75	Reverse light not glowing	0.75	DS4
KD24	15	03-07-2017	10:00:01	03-07-2017	23:30:00	201.50	Hydraulic hose failed	13.5	SS6
KD24	16	08-07-2017	11:30:00	12-07-2017	21:20:00	108.00	Transmission, convertor gears running ne	105.83	SS10
KD24	17	19-07-2017	04:20:00	19-07-2017	07:30:00	151.00	Transmission, convertor gears running ne	3.17	SS10
KD24	18	24-07-2017	06:00:00	24-07-2017	12:30:00	118.50	Alternator belt cut/ missed	6.5	DS4
KD24	19	27-07-2017	08:20:00	27-07-2017	11:45:00	67.83	Brake oil hose failed	3.42	DS1
KD24	20	08-08-2017	07:30:00	08-08-2017	07:40:00	283.75	Suspension hammering	0.17	SS6

KD24	21	11-08-2017	00:50:00	11-08-2017	01:50:00	65.17	Electrical breakdown	1	DS4
KD24	22	20-08-2017	17:20:00	20-08-2017	18:00:00	231.50	Cabin vibration	0.67	SS8
KD24	23	21-08-2017	11:40:00	21-08-2017	16:00:00	17.67	Suspension weak f/l	4.33	SS6
KD24	24	22-08-2017	16:40:27	23-08-2017	00:15:00	24.67	Suspension hammering	7.58	SS6
KD24	25	23-08-2017	16:50:59	23-08-2017	17:10:55	16.60	No side mirror	0.33	SS8
KD24	26	25-08-2017	17:00:45	25-08-2017	17:45:28	47.83	Head lights problem	0.75	DS4
KD24	27	25-08-2017	19:20:27	25-08-2017	19:45:02	1.58	Head lights problem	0.41	DS4
KD24	28	26-08-2017	21:00:21	28-08-2017	13:45:17	25.26	Transmission, convertor gears not upshif	40.75	SS10
KD24	29	30-08-2017	09:30:31	30-08-2017	12:55:36	43.75	Suspension hammering	3.42	SS6
KD24	30	04-09-2017	16:30:00	04-09-2017	18:30:00	123.57	Suspension hammering	2	SS6
KD24	31	05-09-2017	07:30:00	05-09-2017	10:30:00	13.00	Problem occurred in operator	3	SS8
KD24	32	06-09-2017	01:00:13	06-09-2017	01:15:58	14.50	Suspension hammering	0.26	SS6
KD24	33	09-09-2017	07:30:00	09-09-2017	08:20:00	78.23	Tyre air inflation less	0.83	SS9
KD24	34	12-09-2017	07:30:00	12-09-2017	08:30:00	71.17	Bucket operations slow	1	SS6
KD24	35	12-09-2017	16:55:11	12-09-2017	17:00:11	8.42	Reverse light not glowing	0.08	DS4
KD24	36	13-09-2017	03:45:00	13-09-2017	12:00:00	10.75	Tyre punctured	8.25	SS9
KD24	37	15-09-2017	02:15:00	15-09-2017	02:40:00	38.25	Boulder got jammed between rear tyres	0.42	DS2
KD24	38	15-09-2017	16:50:00	15-09-2017	17:30:00	14.17	Suspension hammering	0.67	SS6
KD24	39	16-09-2017	05:30:00	16-09-2017	06:15:00	12.00	Trans indicator bulb glowing continuously instrument panel, gauges	0.75	DS4
KD24	40	16-09-2017	11:30:00	16-09-2017	12:00:00	5.25	Tyre air inflation less	0.5	DS2
KD24	41	19-09-2017	10:00:01	19-09-2017	19:30:00	70.00	Suspension hammering	9.5	SS6
KD24	42	20-09-2017	01:50:00	20-09-2017	20:45:00	6.33	Tyre punctured	18.92	SS9
KD24	43	22-09-2017	07:00:05	22-09-2017	08:20:47	34.25	Tyre air inflation less	1.35	SS9
KD24	44	26-09-2017	15:01:00	28-09-2017	19:00:00	102.67	Diesel leakage	51.98	DS5
KD24	45	29-09-2017	16:00:00	29-09-2017	18:30:00	21.00	Hydraulic oil leakage	2.5	SS6
KD24	46	04-10-2017	16:00:00	04-10-2017	17:00:00	117.50	Reverse light not glowing	1	DS4
KD24	47	05-10-2017	18:00:00	05-10-2017	19:00:00	25.00	Reverse light not glowing	1	DS4
KD24	48	10-10-2017	09:02:00	10-10-2017	09:30:00	110.03	Suspension hammering	0.47	SS6
KD24	49	19-10-2017	05:00:00	19-10-2017	06:00:00	211.50	Electrical breakdown	1	DS4
KD24	50	21-10-2017	09:30:00	21-10-2017	16:00:00	51.50	Initial problem (engine not starting)	6.5	DS4
KD24	51	30-10-2017	08:00:00	30-10-2017	08:30:00	208.00	Electrical breakdown	0.5	DS4

KD24	52	02-11-2017	08:30:50	02-11-2017	12:00:38	72.01	Electrical breakdown	3.5	DS4
KD24	53	05-11-2017	07:30:00	05-11-2017	17:50:00	67.49	Rock ejector missing	10.33	DS2
KD24	54	06-11-2017	15:01:00	06-11-2017	15:02:00	21.18	Hydraulic oil leakage	0.02	SS6
KD24	55	16-11-2017	07:30:00	16-11-2017	12:50:00	232.47	Rock ejector missing	5.33	DS2
KD24	56	18-11-2017	07:30:00	18-11-2017	11:30:00	42.67	Engine oil level low	4	DS5
KD24	57	19-11-2017	15:01:00	19-11-2017	17:00:00	27.52	Hydraulic oil level low in engine	1.98	DS5
KD24	58	19-11-2017	21:45:00	19-11-2017	00:00:00	4.75	Chassis welding	2.25	SS8
					MTBF of KD24	**83.70**	**MTTR of KD24**	**7.486**	
Systems	**No. of failures**	**Start Date**	**Start Time**	**End date**	**End Time**	**TBF, hrs**	**Reasons**	**TTR, hrs**	**Failure Codes**
KD25	1	01-04-2017	08:05:00	01-04-2017	14:00:00	0.00	Transmission, convertor transmission oil	5.92	DS10
KD25	2	10-04-2017	22:49:39	11-04-2017	00:10:12	224.83	Tyre air inflation less	1.34	DS9
KD25	3	11-04-2017	23:00:44	11-04-2017	00:10:39	22.84	Transmission, convertor gears not engaging	1.17	DS10
KD25	4	11-04-2017	09:31:16	23-04-2017	18:00:00	9.34	Lubrication oil leakage in breaks	296.48	DS1
KD25	5	25-04-2017	09:50:50	25-04-2017	14:01:20	39.85	Wheel bolts loose	4.17	DS9
KD25	6	27-04-2017	07:30:32	27-04-2017	11:45:00	41.49	Suspension hammering	4.24	DS6
KD25	7	03-05-2017	23:30:59	03-05-2017	23:55:15	155.77	Electrical breakdown	0.4	DS4
KD25	8	19-05-2017	00:30:00	19-05-2017	00:45:00	360.58	Body welding	0.25	DS8
KD25	9	05-06-2017	19:20:00	05-06-2017	19:45:00	426.58	Lighting problem	0.42	DS4
KD25	10	08-06-2017	15:30:00	08-06-2017	19:10:00	67.75	A / C not working	3.67	DS4
KD25	11	09-06-2017	00:15:00	09-06-2017	13:00:00	5.08	Alternator belt cut/ missed	12.75	DS4
KD25	12	13-06-2017	21:30:00	13-06-2017	22:30:00	104.50	Rock ejector got bend	1	DS2
KD25	13	17-06-2017	20:30:00	17-06-2017	20:50:00	94.00	Lighting problem	0.33	DS4
KD25	14	20-06-2017	15:00:00	20-06-2017	18:50:57	66.17	Tyre punctured	3.85	DS9
KD25	15	24-06-2017	13:30:00	26-06-2017	02:40:00	90.65	Tyre punctured	37.17	DS9
KD25	16	09-07-2017	07:30:00	09-07-2017	11:55:00	316.83	Wheel bolts loose	4.42	DS9
KD25	17	12-07-2017	10:00:00	12-07-2017	11:30:00	70.08	Electrical breakdown	1.5	DS4
KD25	18	16-07-2017	09:15:55	16-07-2017	09:45:40	93.77	Suspension hammering	0.5	DS6
KD25	19	19-07-2017	23:30:00	20-07-2017	00:05:00	85.74	Reverse light not glowing	0.58	DS4
KD25	20	20-07-2017	18:15:00	20-07-2017	18:50:00	18.17	Reverse light not glowing	0.58	DS4
KD25	21	21-07-2017	23:30:00	22-07-2017	00:40:00	28.67	Final drive problem	1.17	DS2
KD25	22	22-07-2017	06:30:00	22-07-2017	11:45:58	5.83	Reverse light not glowing	5.27	DS4

KD25	23	22-07-2017	18:50:00	22-07-2017	19:15:00	7.07	Electrical breakdown	0.42	DS4
KD25	24	24-07-2017	11:45:00	24-07-2017	14:10:00	40.50	Rock ejector got bend	2.42	DS2
KD25	25	30-07-2017	15:30:19	30-07-2017	16:00:25	145.34	Suspension hammering	0.5	DS6
KD25	26	09-08-2017	23:30:00	10-08-2017	11:50:00	247.49	Electrical breakdown	12.33	DS4
KD25	27	18-08-2017	17:00:00	18-08-2017	17:20:00	197.17	Electrical breakdown	0.33	DS4
KD25	28	21-08-2017	09:00:00	21-08-2017	09:30:00	63.67	Tyre got damaged	0.5	DS9
KD25	29	21-08-2017	16:56:51	21-08-2017	17:57:00	7.45	Hoist cylinder hose failure	1.0025	DS6
KD25	30	22-08-2017	07:01:00	22-08-2017	10:30:00	13.07	Wheel bolts loose	3.48	DS2
KD25	31	22-08-2017	23:30:00	23-08-2017	00:15:00	13.00	Lighting problem	0.75	DS4
KD25	32	24-08-2017	07:01:00	24-08-2017	09:50:00	30.77	Exhaust smoke is black	2.82	DS5
KD25	33	24-08-2017	10:15:00	24-08-2017	11:30:00	0.42	Electrical breakdown	1.25	DS4
KD25	34	25-08-2017	18:10:56	25-08-2017	18:20:00	30.68	Electrical breakdown	0.15	DS4
KD25	35	28-08-2017	00:10:00	28-08-2017	01:30:00	53.83	Oil replacement	1.33	DS1
KD25	36	28-08-2017	01:31:00	28-08-2017	02:20:00	0.02	Head lights problem	0.82	DS4
KD25	37	28-08-2017	13:20:21	29-08-2017	00:30:00	11.01	No water in radiator	11.16	DS5
KD25	38	03-09-2017	23:30:54	04-09-2017	00:15:11	143.02	Reverse light not glowing	0.74	DS4
KD25	39	06-09-2017	14:00:00	06-09-2017	16:30:00	61.75	Transmission, convertor propel shaft bro	2.5	DS10
KD25	40	15-09-2017	16:00:00	15-09-2017	16:30:00	215.50	Electrical breakdown	0.5	DS4
KD25	41	23-09-2017	18:20:00	24-09-2017	12:15:00	193.83	Exhaust smoke is black	17.92	DS5
KD25	42	26-09-2017	01:15:55	26-09-2017	01:30:43	37.02	Suspension hammering	0.25	DS6
KD25	43	04-10-2017	06:30:00	04-10-2017	08:00:00	196.99	Lighting problem	1.5	DS4
KD25	44	08-10-2017	10:00:00	08-10-2017	12:00:00	98.00	Suspension hammering	2	SS6
KD25	45	09-10-2017	07:30:49	09-10-2017	10:45:32	19.51	Suspension hammering	3.25	DS5
KD25	46	10-10-2017	09:00:00	10-10-2017	19:00:00	22.24	Suspension hammering	10	DS6
KD25	47	17-10-2017	07:30:00	17-10-2017	08:15:00	156.50	Tyre air inflation less	0.75	DS2
KD25	48	17-10-2017	09:00:00	17-10-2017	13:00:00	0.75	Suspension oil leakage f/l	4	DS6
KD25	49	24-10-2017	08:20:00	24-10-2017	08:40:00	163.33	Electrical breakdown	0.33	DS4
KD25	50	24-10-2017	18:20:19	24-10-2017	23:50:00	9.67	Suspension hammering	5.49	DS6
KD25	51	25-10-2017	19:40:53	25-10-2017	20:50:13	19.85	Suspension hammering	1.16	DS6
KD25	52	25-10-2017	22:15:59	25-10-2017	22:41:36	1.43	Ladders and Railings damage	0.43	DS8
KD25	53	26-10-2017	05:00:00	26-10-2017	10:30:00	6.31	Suspension oil leakage r/l	5.5	DS6
KD25	54	26-10-2017	19:00:52	26-10-2017	20:00:01	8.51	Suspension hammering	0.99	DS6

KD25	55	29-10-2017	23:30:00	29-10-2017	00:00:00	75.50	Electrical breakdown	0.5	DS4
KD25	56	30-10-2017	11:30:00	02-11-2017	17:45:00	11.50	Suspension hammering	78.25	DS6
KD25	57	02-11-2017	18:40:00	02-11-2017	23:55:00	0.917	Tyre air inflation less	5.25	DS2
KD25	58	03-11-2017	20:40:00	03-11-2017	23:55:00	20.750	Electrical breakdown	3.25	DS4
KD25	59	04-11-2017	13:00:42	04-11-2017	17:15:00	13.095	Electrical breakdown	4.24	DS4
KD25	60	04-11-2017	23:30:00	04-11-2017	23:55:00	6.250	Electrical breakdown	0.42	DS4
KD25	61	05-11-2017	09:45:00	05-11-2017	11:45:00	9.833	Bucket hoisting problem	2	DS1
KD25	62	05-11-2017	17:30:00	05-11-2017	23:40:00	5.750	Hydraulic oil level low	6.17	DS5
KD25	63	06-11-2017	08:15:00	07-11-2017	22:45:00	8.583	Suspension hammering	38.5	DS6
KD25	64	08-11-2017	16:20:00	08-11-2017	16:50:00	17.583	A / c not working	0.5	DS4
KD25	65	08-11-2017	20:30:00	09-11-2017	16:30:00	3.667	Cabin door glass problem	20	DS8
KD25	66	12-11-2017	17:00:39	12-11-2017	17:30:55	72.511	A / c not working	0.5	DS4
KD25	67	17-11-2017	16:30:00	17-11-2017	19:00:00	118.985	A / c not working	2.5	DS4
KD25	68	18-11-2017	09:20:00	18-11-2017	11:30:00	14.333	Electrical breakdown	2.17	DS4
KD25	69	09-12-2017	15:00:00	09-12-2017	15:01:00	507.500	Hydraulic oil leakage	0.02	DS1
KD25	70	13-12-2017	01:00:00	13-12-2017	01:30:00	81.983	Electrical breakdown	0.5	DS4
KD25	71	16-12-2017	06:50:00	16-12-2017	13:00:00	77.333	Tyre got damaged	6.17	DS2
KD25	72	18-12-2017	04:30:05	18-12-2017	05:42:47	39.501	Transmission, convertor gears not engaging	1.21	DS10
KD25	73	25-12-2017	23:30:00	26-12-2017	00:15:00	185.787	Lighting problem	0.75	DS2
KD25	74	30-12-2017	15:00:00	30-12-2017	17:30:00	110.750	Final drive problem	2.5	DS2
					MTBF of KD25	**80.085**	**MTTR of KD25**	**8.907**	
Systems	**No. of failures**	**Start Date**	**Start Time**	**End date**	**End Time**	**TBF, hrs**	**Reasons**	**TTR, hrs**	**Failure Codes**
KD26	1	10-04-2017	07:30:00	10-04-2017	10:50:00	0.000	Cabin vibration	3.33	DS8
KD26	2	12-04-2017	15:00:00	12-04-2017	20:30:00	52.167	Brake oil hose failed	5.5	DS1
KD26	3	13-04-2017	05:15:13	13-04-2017	18:30:00	8.754	Electrical breakdown	13.25	DS4
KD26	4	14-04-2017	06:30:59	14-04-2017	18:00:00	12.016	Universal joint broken	11.48	DS2
KD26	5	22-04-2017	01:50:00	22-04-2017	10:20:00	175.833	Electrical breakdown	8.5	DS4
KD26	6	01-05-2017	18:10:00	01-05-2017	19:00:00	223.833	Electrical breakdown	0.83	DS4
KD26	7	05-05-2017	10:15:00	05-05-2017	20:20:00	87.250	Tyre punctured	10.08	DS9
KD26	8	06-05-2017	12:20:00	06-05-2017	12:45:00	16.000	Catwalk railing damaged	0.42	DS8
KD26	9	10-05-2017	16:44:06	10-05-2017	16:45:00	99.985	O ring failure	0.01	DS9

KD26	10	15-05-2017	12:00:00	15-05-2017	20:45:00	115.250	Tyre O-ring failed	8.75	DS9
KD26	11	16-05-2017	23:30:00	16-05-2017	23:55:00	26.750	Grease container empty	0.42	DS5
KD26	12	17-05-2017	10:00:00	17-05-2017	11:45:00	10.083	Electrical breakdown	1.75	DS4
KD26	13	19-05-2017	00:15:00	19-05-2017	00:35:00	36.500	Reverse light not glowing	0.33	DS4
KD26	14	11-07-2017	07:30:00	11-07-2017	16:20:41	1278.917	Hydraulic oil leakage	8.84	DS6
KD26	15	16-07-2017	10:01:52	16-07-2017	12:20:28	113.686	Ladder / railing damaged	2.31	DS8
KD26	16	21-07-2017	23:30:00	22-07-2017	00:10:00	131.159	Reverse light not glowing	0.67	DS4
KD26	17	22-07-2017	07:30:35	22-07-2017	23:50:00	7.343	Problem occurred in grease injector	16.32	DS2
KD26	18	23-07-2017	10:00:00	23-07-2017	16:00:00	10.167	Electrical breakdown	6	DS4
KD26	19	25-07-2017	07:30:00	25-07-2017	09:30:00	39.500	Wheel bolts loose	2	DS9
KD26	20	25-07-2017	20:30:00	25-07-2017	21:00:00	11.000	Reverse light not glowing	0.5	DS4
KD26	21	03-08-2017	15:18:38	03-08-2017	20:19:26	210.311	Tyre got damaged	5.01	DS9
KD26	22	18-08-2017	20:30:00	18-08-2017	21:00:00	360.176	Head lights problem	0.5	DS4
KD26	23	18-08-2017	23:40:00	19-08-2017	13:20:00	2.667	Wiring short	13.67	DS4
KD26	24	20-08-2017	00:30:47	20-08-2017	08:40:00	11.180	Head lights problem	8.15	DS4
KD26	25	20-08-2017	19:30:00	20-08-2017	23:30:00	10.833	Lighting problem	4	DS4
KD26	26	21-08-2017	19:30:00	21-08-2017	23:00:00	20.000	Lighting problem	3.5	DS4
KD26	27	25-08-2017	16:00:08	25-08-2017	23:45:00	89.002	Ladder / railing damaged	7.75	DS8
KD26	28	29-08-2017	16:30:00	29-08-2017	18:00:00	88.750	Problem occurred in operator	1.5	DS8
KD26	29	30-08-2017	11:01:40	30-08-2017	16:15:00	17.028	Suspension oil leakage r/r	5.22	DS6
KD26	30	02-09-2017	04:20:00	02-09-2017	04:40:00	60.083	Electrical breakdown	0.33	DS4
KD26	31	02-09-2017	10:00:00	02-09-2017	13:00:00	5.333	Cabin vibration	3	DS8
KD26	32	07-09-2017	08:45:00	07-09-2017	09:40:00	115.750	A / c not working	0.92	DS4
KD26	33	14-09-2017	11:50:01	15-09-2017	22:31:00	170.167	Exhaust gases leakage	34.68	DS5
KD26	34	23-09-2017	22:00:00	24-09-2017	15:00:00	191.483	Tyre got damaged	17	DS2
KD26	35	05-10-2017	09:20:00	05-10-2017	09:40:00	258.333	Electrical breakdown	0.33	DS4
KD26	36	07-10-2017	23:30:00	08-10-2017	00:30:00	61.833	Head lights problem	1	DS4
KD26	37	09-10-2017	12:00:00	09-10-2017	17:15:00	35.500	Alternator belt cut/ missed	5.25	DS4
KD26	38	14-10-2017	00:50:00	14-10-2017	01:10:00	103.583	Lighting problem	0.33	DS4
KD26	39	14-10-2017	07:30:58	14-10-2017	15:30:00	6.349	Transmission, convertor gears not engaging	7.98	DS10
KD26	40	25-10-2017	18:30:04	25-10-2017	22:00:11	267.001	Parking brake not functioning properly	3.5	DS1
KD26	41	27-10-2017	23:30:00	27-10-2017	23:55:00	49.497	Lighting problem	0.42	DS4

KD26	42	02-11-2017	04:45:00	02-11-2017	05:10:00	124.833	Electrical breakdown	0.42	DS4
KD26	43	06-11-2017	16:00:00	06-11-2017	19:00:00	106.833	Catwalk railing damaged	3	DS8
KD26	44	12-11-2017	18:20:27	12-11-2017	20:30:42	143.341	Head lights problem	2.17	DS4
KD26	45	18-11-2017	06:10:00	30-11-2017	12:00:00	129.655	Transmission, convertor transmission gauge	293.83	DS10
KD26	46	03-12-2017	12:15:00	03-12-2017	16:00:43	72.250	Problem occurred in grease injector	3.76	DS5
KD26	47	04-12-2017	23:30:00	05-12-2017	00:35:00	31.488	Lighting problem	1.08	DS4
KD26	48	05-12-2017	07:30:00	05-12-2017	17:00:53	6.917	No side mirror	9.51	DS8
KD26	49	07-12-2017	16:35:38	07-12-2017	23:30:00	47.579	Suspension hammering	7.24	DS6
KD26	50	07-12-2017	23:50:00	08-12-2017	00:25:00	0.333	Lighting problem	0.92	DS4
KD26	51	08-12-2017	18:00:00	08-12-2017	19:00:00	17.583	Electrical breakdown	1	DS4
KD26	52	10-12-2017	07:30:09	10-12-2017	10:00:00	36.503	Catwalk railing damaged	2.5	DS8
KD26	53	11-12-2017	07:30:00	11-12-2017	23:55:00	21.500	Catwalk railing damaged	16.42	DS8
KD26	54	12-12-2017	02:00:00	12-12-2017	02:20:00	2.083	Electrical breakdown	0.33	DS4
KD26	55	12-12-2017	15:30:00	12-12-2017	16:45:00	13.167	Rear view mirror broken	1.25	DS8
KD26	56	13-12-2017	15:01:00	13-12-2017	20:00:00	22.267	Rear view mirror broken	4.98	DS8
KD26	57	13-12-2017	23:30:00	14-12-2017	00:30:00	3.500	Electrical breakdown	1	DS4
KD26	58	16-12-2017	17:00:00	17-12-2017	00:05:00	64.500	Initial problem (engine not starting)	7.08	DS4
					MTBF of KD26	**93.714**	**MTTR of KD26**	**10.031**	

ANNEXURE-B

B.1 Match factor of shovel and dumper in surface coal mine

Production target = 0.2 MT per day

Bucket capacity = 12 Cubic meters

Dumper capacity = 100 Tons

Density of the coal = 1346 Kg/m^3

Bucket factor = 0.9 (90%)

Actual bucket capacity = 12 m^3 × 1346 Kg/m^3 × 0.9

= 16152Kg

=16152 × 0.001 Tons

= 16.152 Tons

Let, Scoring time of the shovel = 15 Sec

Swing time towards the dumper = 10 Sec

Loading time = 10 sec

Swing back = 10 Sec

Cycle time the shove = 15+10+10+10 = 45 Sec

No. of swings requited to load dumper = $\frac{\text{Actual Capacity of Dumper}}{\text{Actual Bucket Capacity of the shovel}}$

$= \frac{100\ T}{16.152} = 6.19 \cong 6$

Dumper capacity = 100 Tons

Actual dumper capacity = 95 Tons

Actual distance = 2.2 Km

Speed of the dumper with load = 19.5 Km/hours

Speed of the dumper without load = 21.5 Km/hours

Total haulage time = $\left[\frac{2 \times 3600}{19.5}\right] + \left[\frac{2 \times 3600}{21.5}\right] = 704.11$ Sec

Let's, Loading time of the dumper at face = 40 Sec

Spotting time of the dumper at face = 10 Sec

Waiting time of the dumper at face = 10 Sec

Spotting time of the dumper at discharge = 10 Sec

Discharge time = 33 Sec

Loading time of the dumper = No. of swing of the shovel × Cycle time of the shovel

= 6 × 45 = 270 Sec

Cycle time of the dumper = 704.11 + 40 + 10 + 10 + 10 + 33 +270 = 1077.11 Sec

No. of trips made by dumper in hours = $\frac{60 \times 60}{1077.11} = 3.3 \cong 3$ trips

Hourly production of the dumper = 3 × 95 = 285 Tons/hours

No. of dumpers required for shovel = $\frac{\text{Hourly Production of Shovel}}{\text{Hourly Production of Dumper}}$

Hourly production of shovel = $\frac{60 \times 60 \times 16.152}{45} = 1292$ Tons/hours

Let's, No. of working hours in day = 18 hours

One day production of shovel = 1292 × 18 = 23256 Tons/Shovel-day

No. of shovel required = $\frac{0.2 \text{ MT}}{23256} = 8.5 \cong 8$

No. of dumpers required for shovel = $\frac{\text{Hourly Production of Shovel}}{\text{Hourly Production of Dumper}} = \frac{1292 \text{ Tons}}{285 \text{ Tons}} = 4.5 \cong 4$

Total No. of dumpers = 4 × 8 = 32 dumpers

Total No. of shovel = 8

Match factor for the given coal mine is = 1:4 (One shovel and Four dumpers)

B.2 Match factor of shovel and dumper in surface iron ore mine

Production target = 26, 000 T per day

Bucket capacity = 4.3 Cubic meters

Dumper capacity = 40 Tons

Density of the iron ore = 2.5 Ton/m^3

Bucket factor = 0.9 (90%)

Actual bucket capacity = 4.3 m^3 × 2.5 T/m^3 × 0.9

= 9.675Ton

Let, Scoring time of the shovel = 15 Sec

Swing time towards the dumper = 10 Sec

Loading time = 10 sec

Swing back = 10 Sec

Cycle time the shove = 15+10+10+10 = 45 Sec

No. of swings requited to load dumper = $\frac{\text{Actual Capacity of Dumper}}{\text{Actual Bucket Capacity of the shovel}}$

$$= \frac{40\ T}{9.675} = 4.1 \ \cong 4$$

Dumper capacity = 40 Tons

Actual dumper capacity = 36.5 Tons

Actual distance = 0.5 Km

Speed of the dumper with load = 18 Km/hours

Speed of the dumper without load = 20.5 Km/hours

Total haulage time = $\left[\frac{0.5 \times 3600}{18}\right] + \left[\frac{0.5 \times 3600}{20.5}\right] = 187.8$ Sec

Let's, Loading time of the dumper at face = 35 Sec

Spotting time of the dumper at face = 10 Sec

Waiting time of the dumper at face = 10 Sec

Spotting time of the dumper at discharge = 10 Sec

Discharge time = 33 Sec

Loading time of the dumper = No. of swing of the shovel × Cycle time of the shovel

= 4 × 45 = 180 Sec

Cycle time of the dumper = 187.8 + 35 + 10 + 10 + 10 + 33 +180 = 465.8 Sec

No. of trips made by dumper in hours = $\frac{60 \times 60}{465.8} = 7.7 \cong 8$ trips

Hourly production of the dumper = 7 × 36.5 = 255.5 Tons/hours

No. of dumpers required for shovel = $\frac{\text{Hourly Production of Shovel}}{\text{Hourly Production of Dumper}}$

Hourly production of shovel = $\frac{60 \times 60 \times 9.675}{45} = 774 \text{ Tons/hours}$

Let's, No. of working hours in day = 13 hours

One day production of shovel = 774 × 13 = 10, 062 Tons/Shovel-day

No. of shovel required = $\frac{26{,}000\ \text{T}}{10{,}062} = 2.5 \cong 3$

No. of dumpers required for shovel = $\frac{\text{Hourly Production of Shovel}}{\text{Hourly Production of Dumper}} = \frac{774}{255.5} = 3.029 \cong 3$

Total No. of dumpers = 3 × 3 = 9 dumpers

Total No. of shovel = 3

Match factor for the given coal mine is = 1:3 (One shovel and Three dumpers)

B.3 Match factor of shovel and dumper in surface Limestone mine

Production target = 30, 000T per day

Bucket capacity = 6.5 Cubic meters

Dumper capacity = 55 Tons

Density of the limestone = 2711 Kg /m^3 = 2.711Tons/m^3

Bucket factor = 0.9 (90%)

Actual bucket capacity = 6.5 m^3 × 2.711 T/m^3 × 0.9

= 15.86 Ton

Let, Scoring time of the shovel = 20 Sec

Swing time towards the dumper = 15 Sec

Loading time = 10 sec

Swing back = 10 Sec

Cycle time the shove = 20+15+10+10 = 55 Sec

No. of swings requited to load dumper = $\frac{\text{Actual Capacity of Dumper}}{\text{Actual Bucket Capacity of the shovel}}$

$= \frac{50\ T}{15.86} = 3.5 \cong 4$

Dumper capacity = 55 Tons

Actual dumper capacity = 50 Tons

Actual distance = 3 Km

Speed of the dumper with load = 18 Km/hours

Speed of the dumper without load = 22 Km/hours

Total haulage time = $\left[\frac{1 \times 3600}{18}\right] + \left[\frac{1 \times 3600}{22}\right] = 363.63$ Sec

Let's, Loading time of the dumper at face = 35 Sec

Spotting time of the dumper at face = 10 Sec

Waiting time of the dumper at face = 10 Sec

Spotting time of the dumper at discharge = 10 Sec

Discharge time = 33 Sec

Loading time of the dumper = No. of swing of the shovel × Cycle time of the shovel

= 4 × 55 = 190 Sec

Cycle time of the dumper = 363.63 + 35 + 10 + 10 + 10 + 33 +190 = 651.63 Sec

No. of trips made by dumper in hours = $\frac{60 \times 60}{651.63} = 5.5 \cong 6$ trips

Hourly production of the dumper = 6 × 50 = 300 Tons/hours

No. of dumpers required for shovel = $\frac{\text{Hourly Production of Shovel}}{\text{Hourly Production of Dumper}}$

Hourly production of shovel = $\frac{60 \times 60 \times 15.86}{55} = 1038.1 \text{ Tons/hours}$

Lets No. of working hours in day = 14 hr

One day production of shovel = 1038.1 × 14 = 14,533.53 Tons/Shovel-day

No. of shovel required = $\frac{30{,}000T}{14{,}533.53} = 2.06 \cong 2$

No. of dumpers required for shovel = $\frac{\text{Hourly Production of Shovel}}{\text{Hourly Production of Dumper}} = \frac{1038.1}{300} = 3.4 \cong 3$

Total No. of dumpers = 3 × 2 = 6 dumpers

Total No. of shovel = 2

Match factor for the given coal mine is = 1:3 (One shovel and Three dumpers)

Annexure-C

C.1 Failure details of shovel

Figure C.1 Arm Cylinder

Figure C.2 Boom cylinder

Figure C.3 Bucket failure

Figure C.4 Cab and its attachments

Figure C3.5 Electrical subsystem

Figure C.6 Engine

Figure C.7 Hydraulic subsystem

Figure C.8 Power Trains

Figure C.9 Structural subsystem

Figure C.10 Undercarriage and frame

C.2 Failure details of dumpers

Figure C.11 braking subsystem

Figure C.12 Differential subsystem

Figure C.13 Drive train

Figure C.14 Electrical subsystem

Figure C.15 Engine

Figure C.16 Hydraulic suspension subsystem

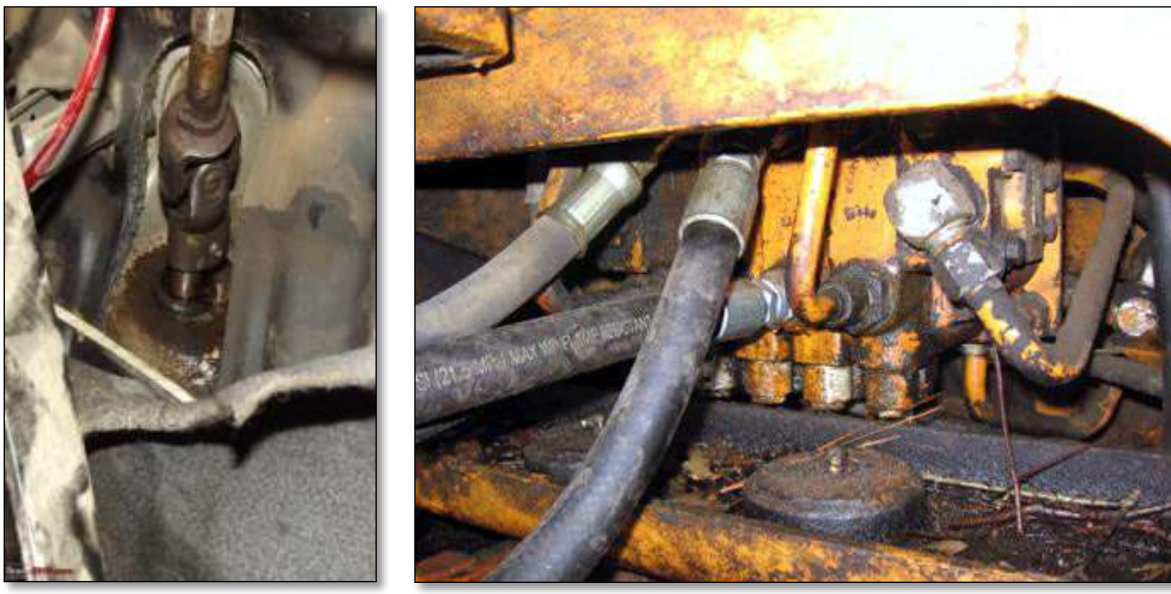

Figure C.17 steering subsystem

Figure C.18 Structural subsystem

Figure C.19 Tires and Rims

Figure C.20 Transmission subsystem

Annexure-D

D.1 Reliability block diagrams (RBD) of shovel-dumper system

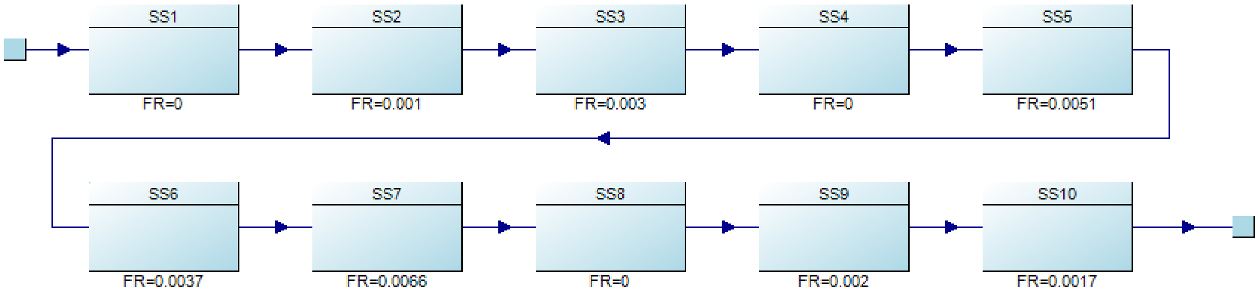

Figure D.1 RBD of shovel – KS2 (Surface coal mine)

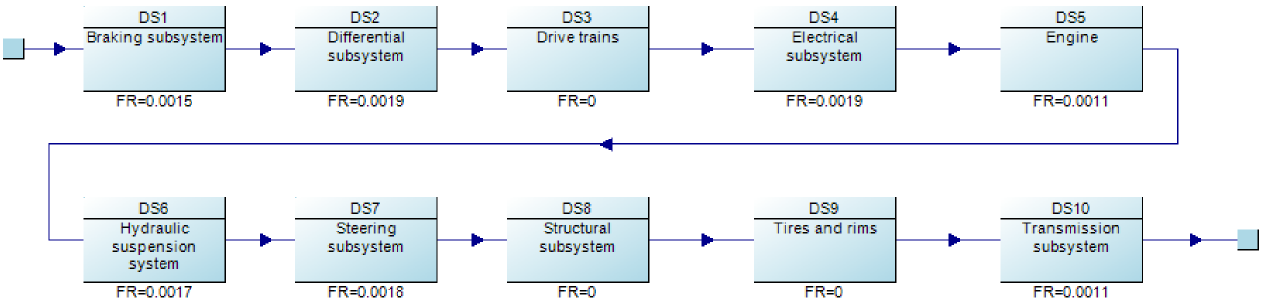

Figure D.2 RBD of dumper – BD4 (Surface coal mine)

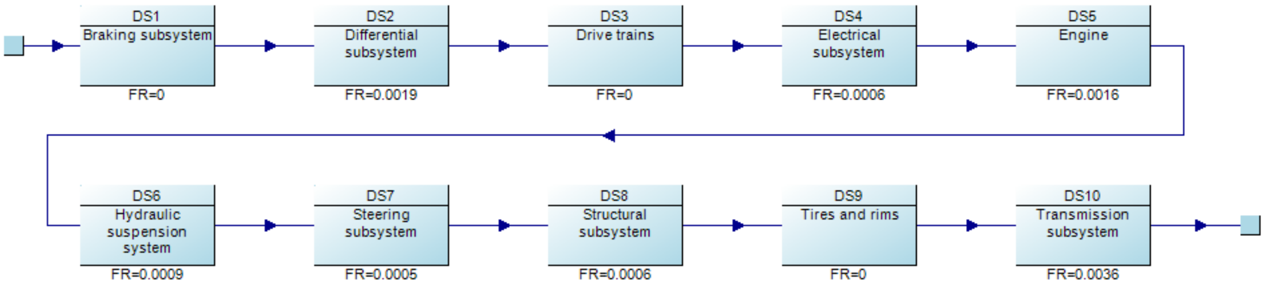

Figure D.3 RBD of dumper – BD5 (Surface coal mine)

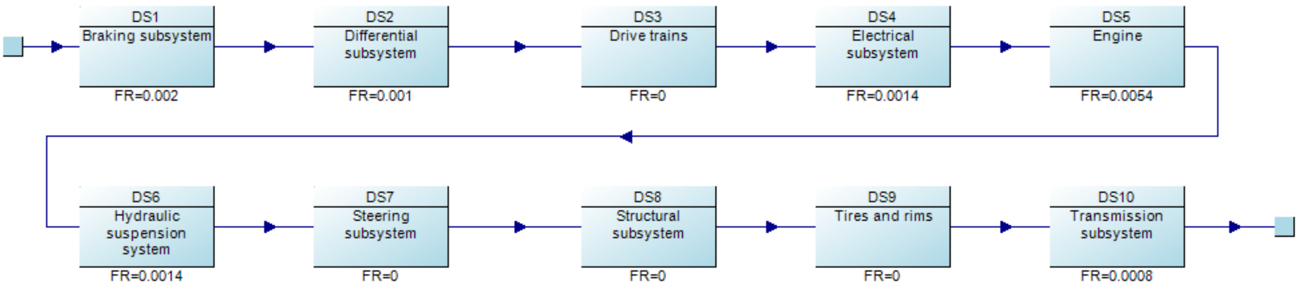

Figure D.4 RBD of dumper – BD6 (Surface coal mine)

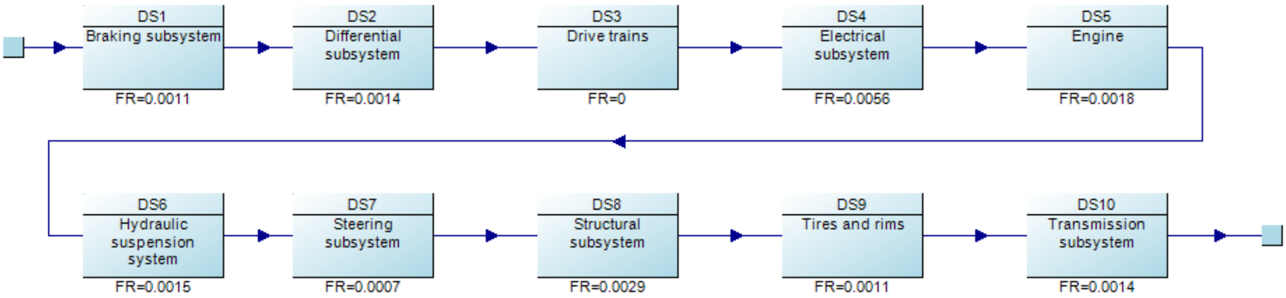

Figure D.5 RBD of dumper – KD7 (Surface coal mine)

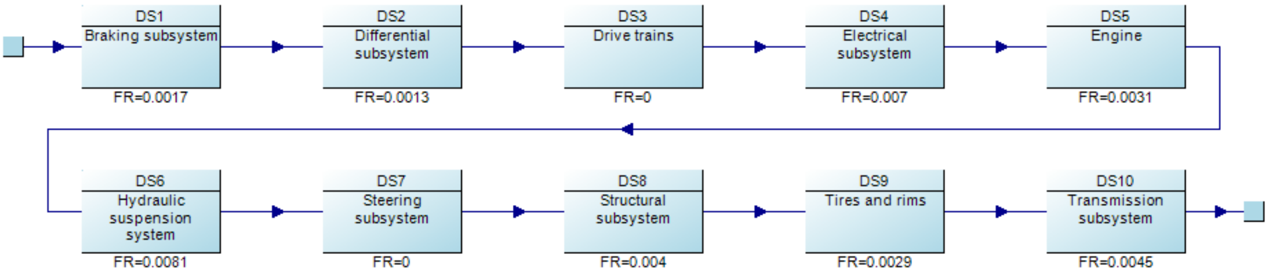

Figure D.6 RBD of dumper – KD8 (Surface coal mine)

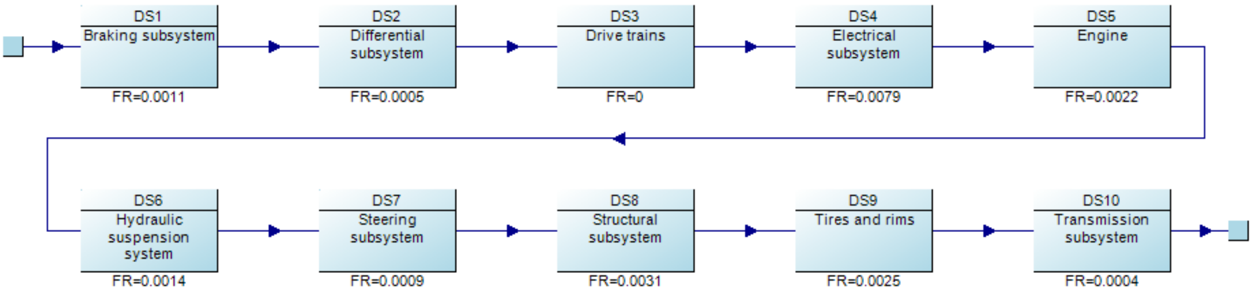

Figure D.7 RBD of dumper – KD9 (Surface coal mine)

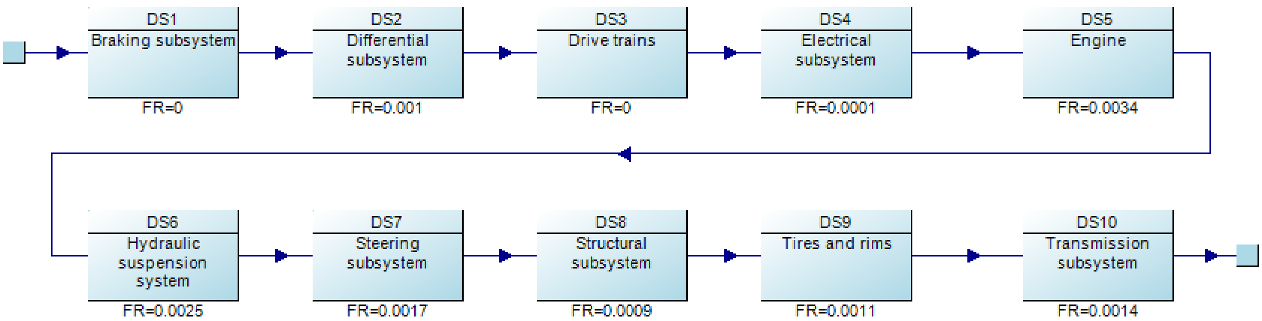

Figure D.8 RBD of dumper – KD10 (Surface coal mine)

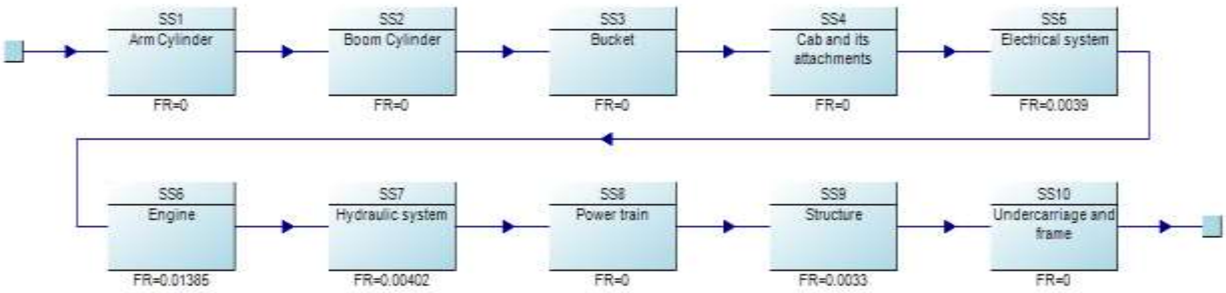

Figure D.9 RBD of shovel – KS12 (Surface iron ore mine)

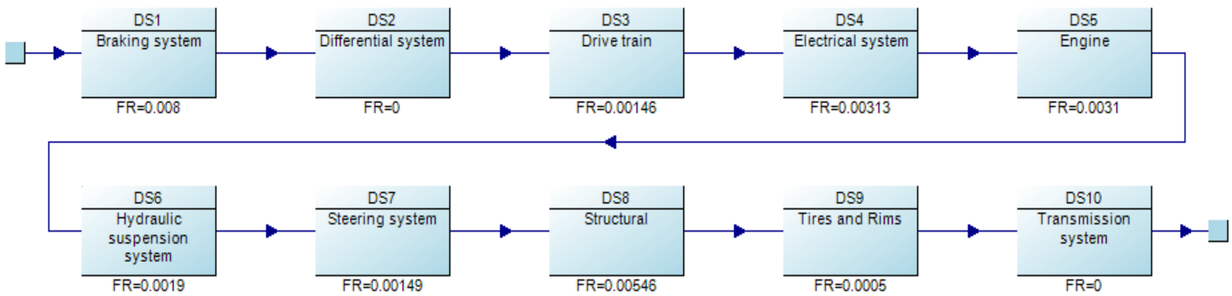

Figure D.10 RBD of dumper – BD14 (Surface iron ore mine)

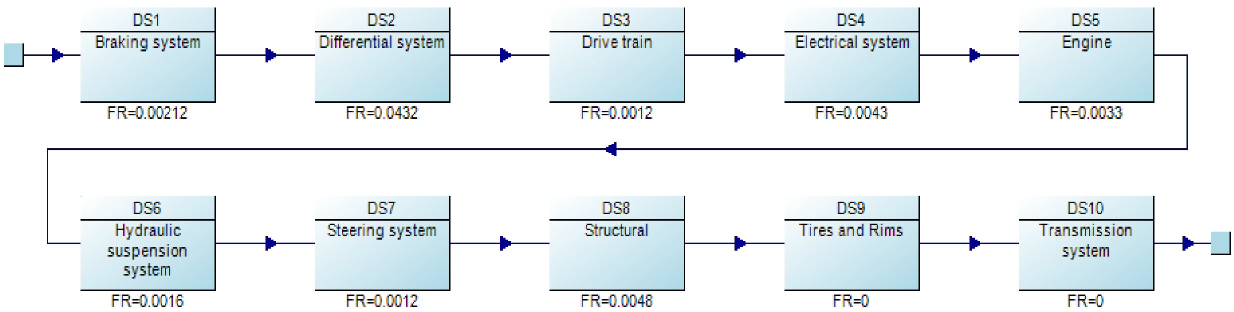

Figure D.11 RBD of dumper – BD15 (Surface iron ore mine)

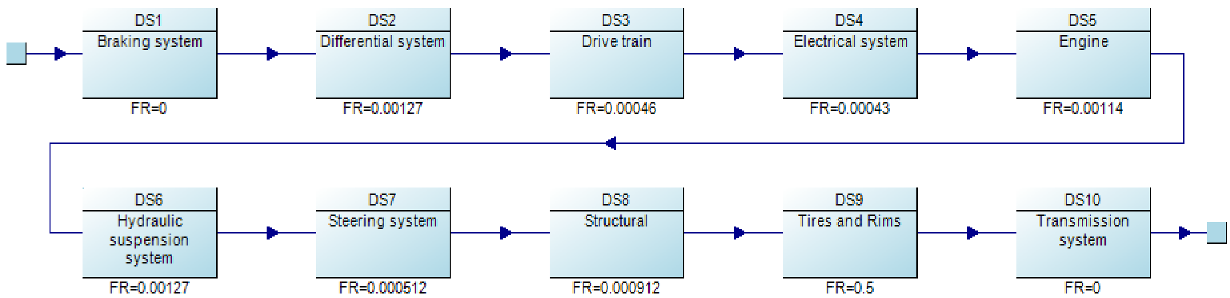

Figure D.12 RBD of dumper – KD16 (Surface iron ore mine)

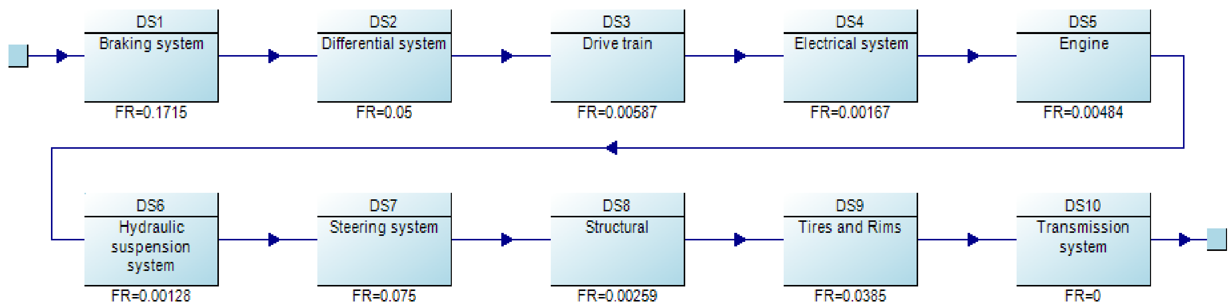

Figure D.13 RBD of dumper – KD17 (Surface iron ore mine)

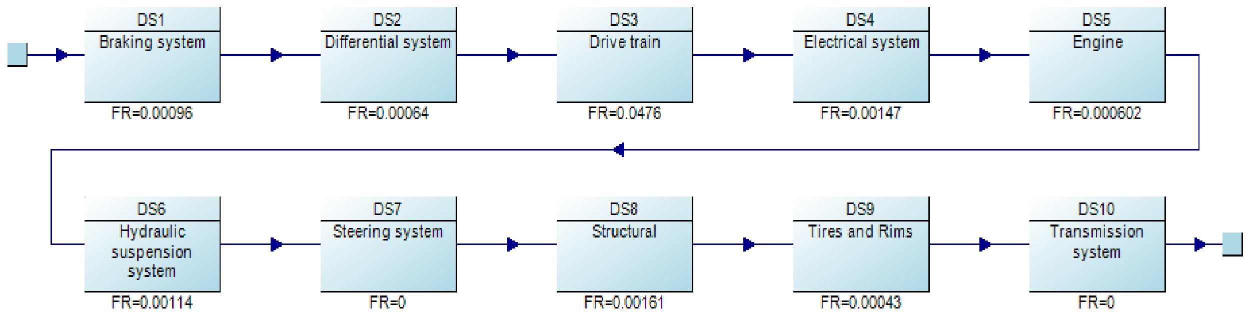

Figure D.14 RBD of dumper – KD18 (Surface iron ore mine)

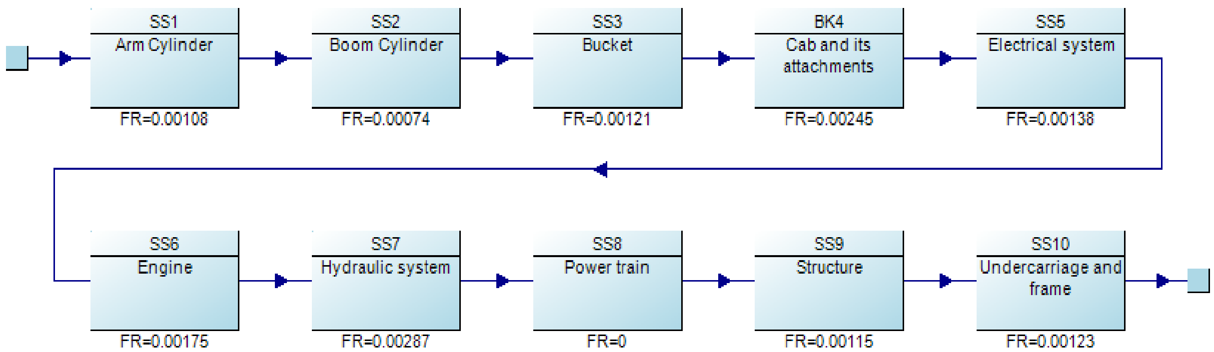

Figure D.15 RBD of shovel – KS20 (Surface Limestone mine)

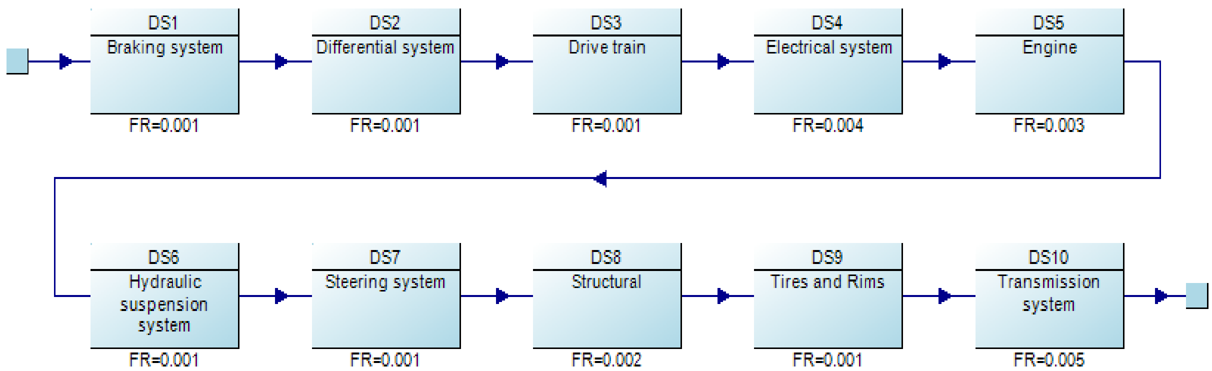

Figure D.16 RBD of dumper – BD22 (Surface Limestone mine)

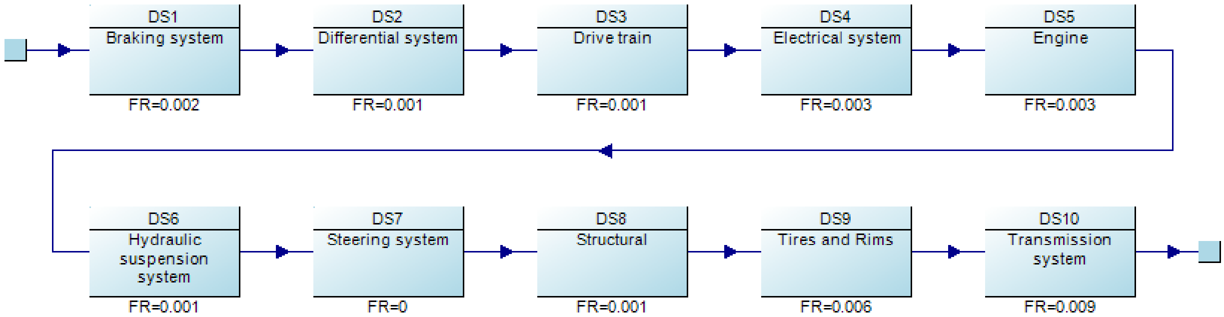

Figure D.17 RBD of dumper – BD23 (Surface Limestone mine)

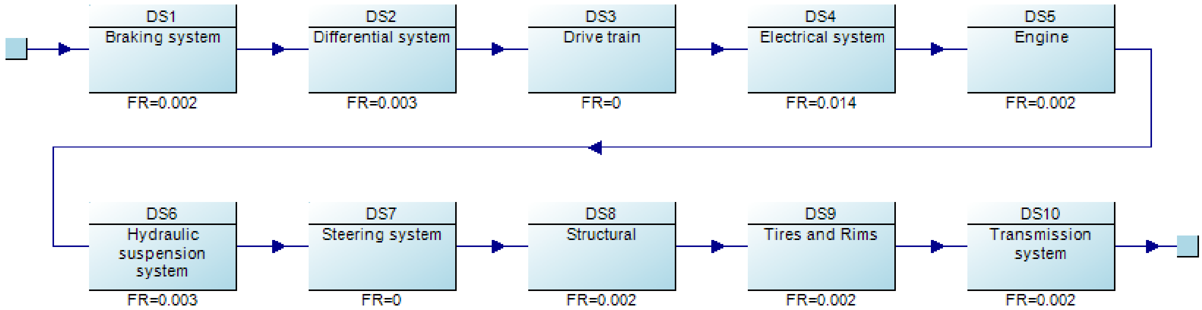

Figure D.18 RBD of dumper – KD24 (Surface Limestone mine)

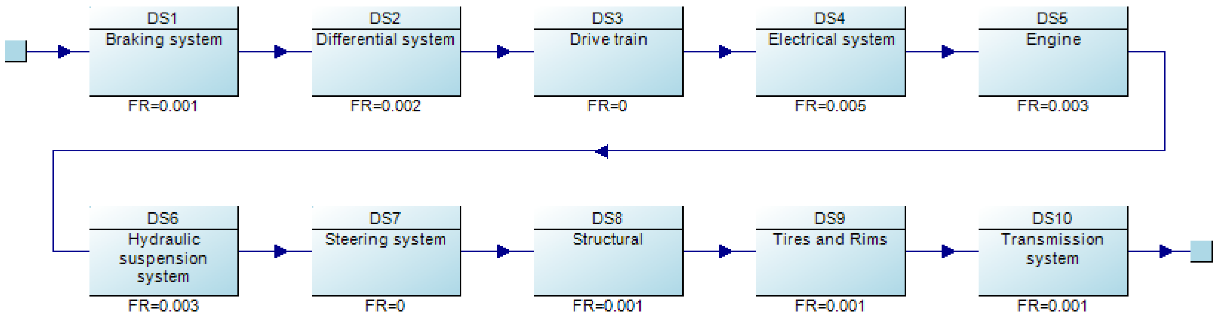

Figure D.19 RBD of dumper – KD25 (Surface Limestone mine)

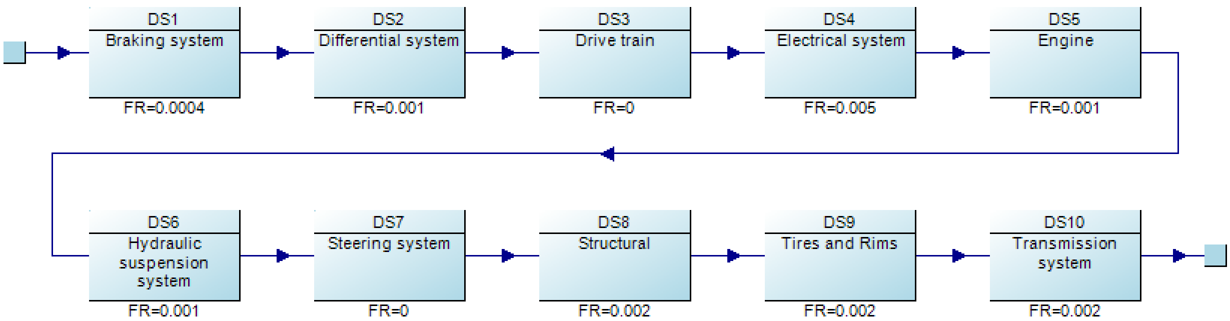

Figure D.20 RBD of dumper – KD26 (Surface Limestone mine)

D.2 Fussell-Vesely Importance of shovel-dumper system

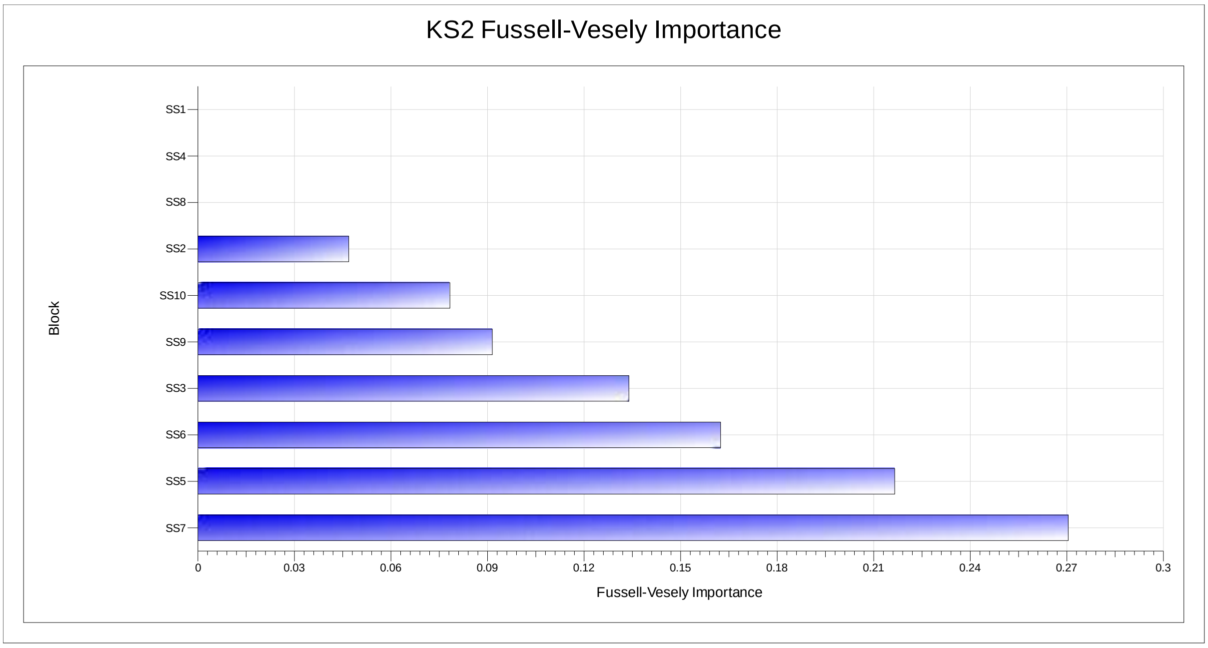

Figure D.21 Fussell-Vesely Importance of KS2 (Surface coal mine)

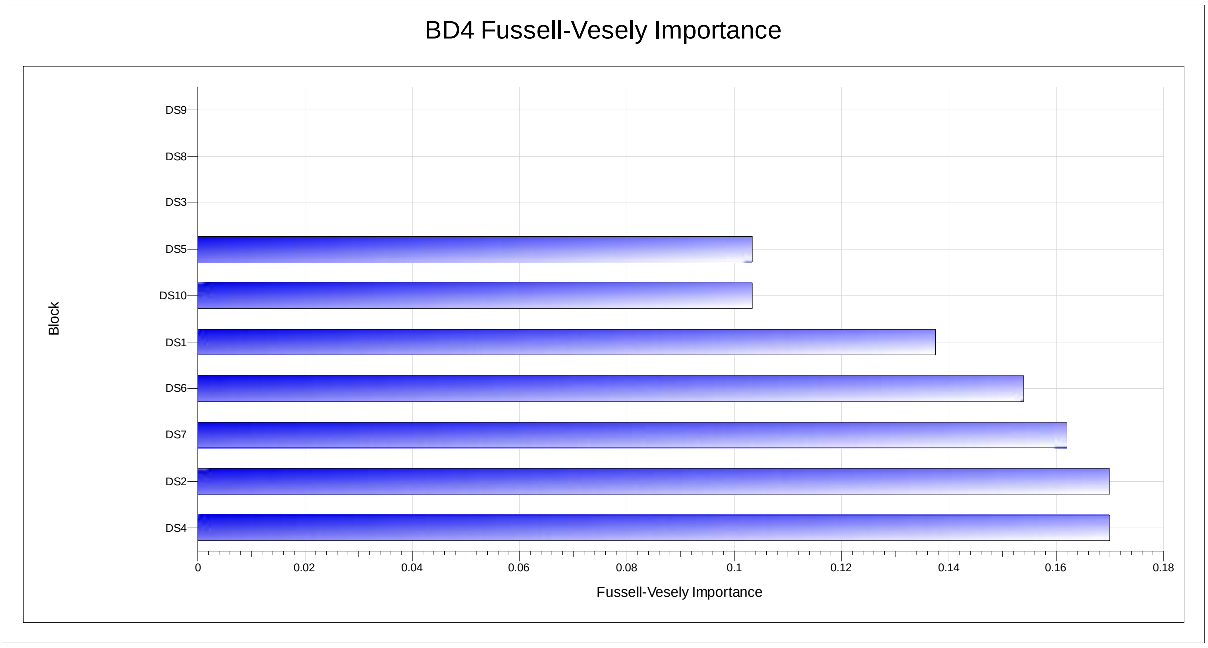

Figure D.22 Fussell-Vesely Importance of BD4 (Surface coal mine)

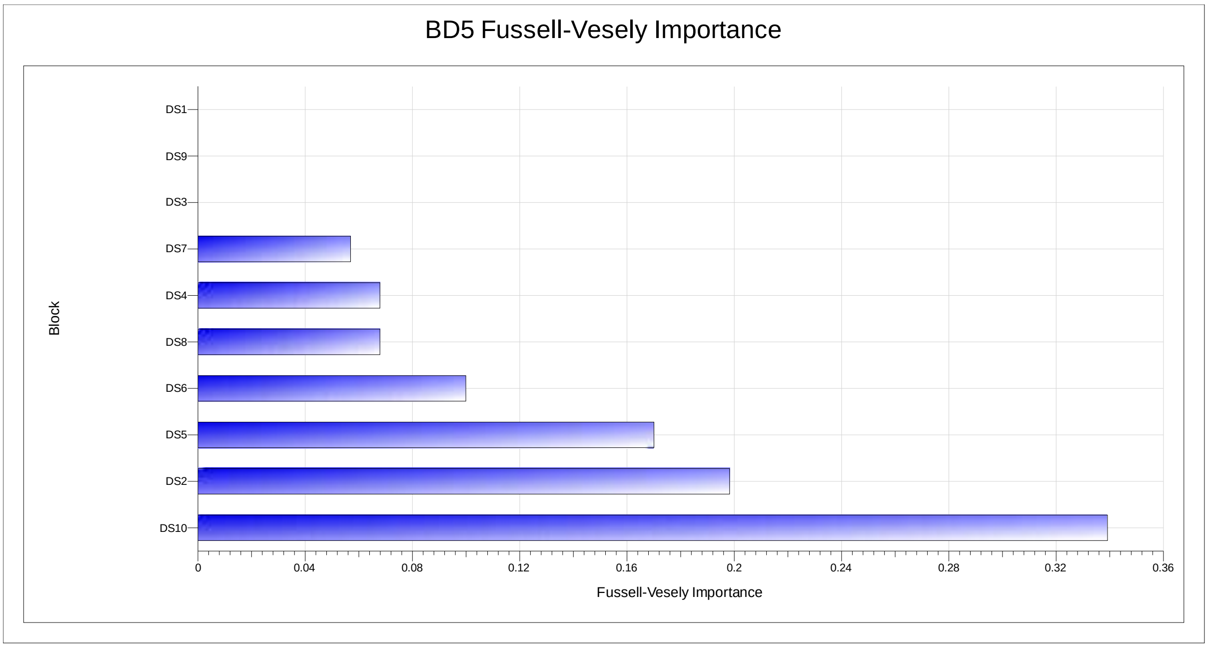

Figure D.23 Fussell-Vesely Importance of BD5 (Surface coal mine)

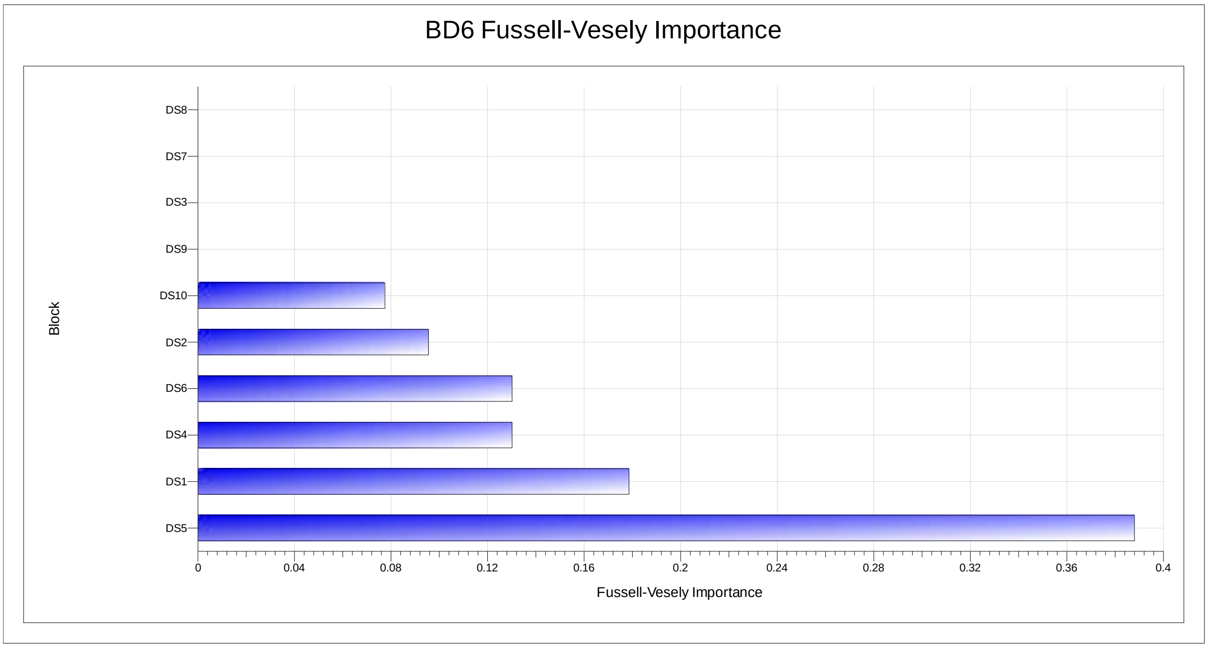

Figure D.24 Fussell-Vesely Importance of BD6 (Surface coal mine)

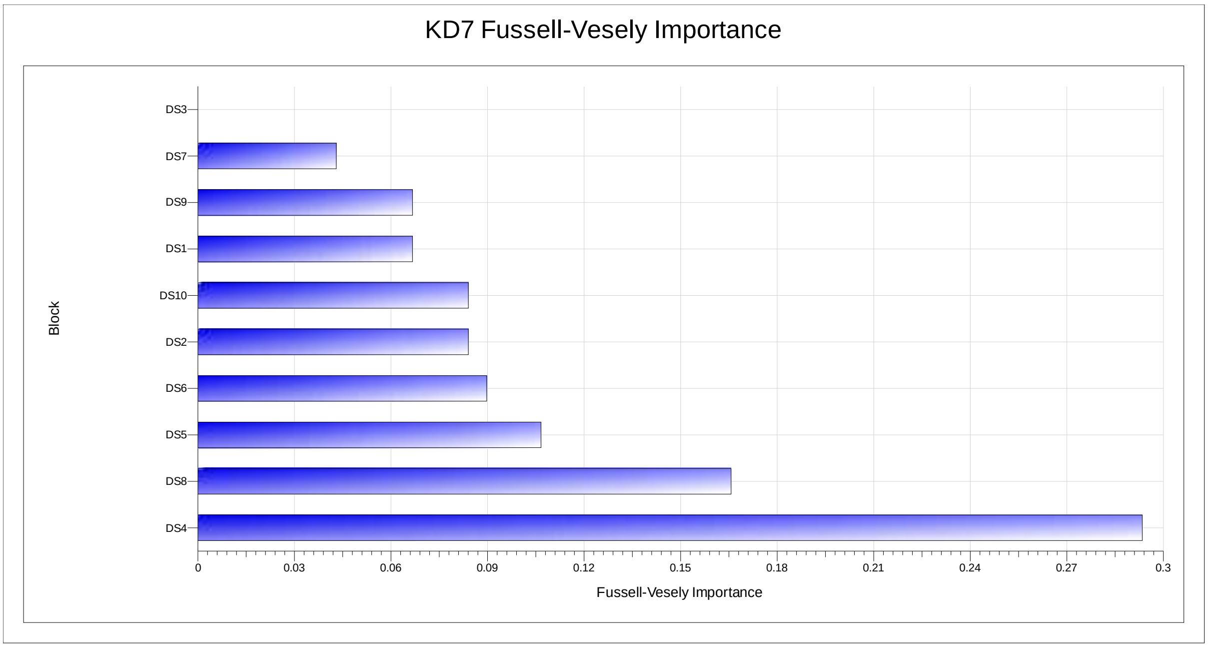

Figure D.25 Fussell-Vesely Importance of KD7 (Surface coal mine)

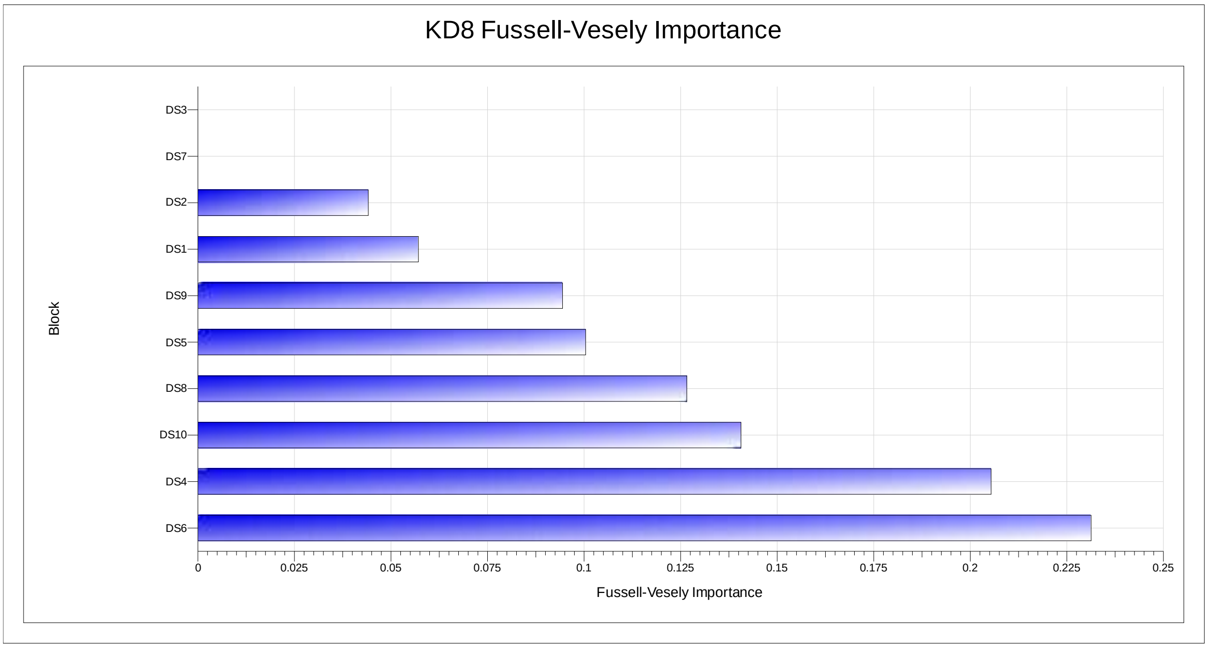

Figure D.26 Fussell-Vesely Importance of KD8 (Surface coal mine)

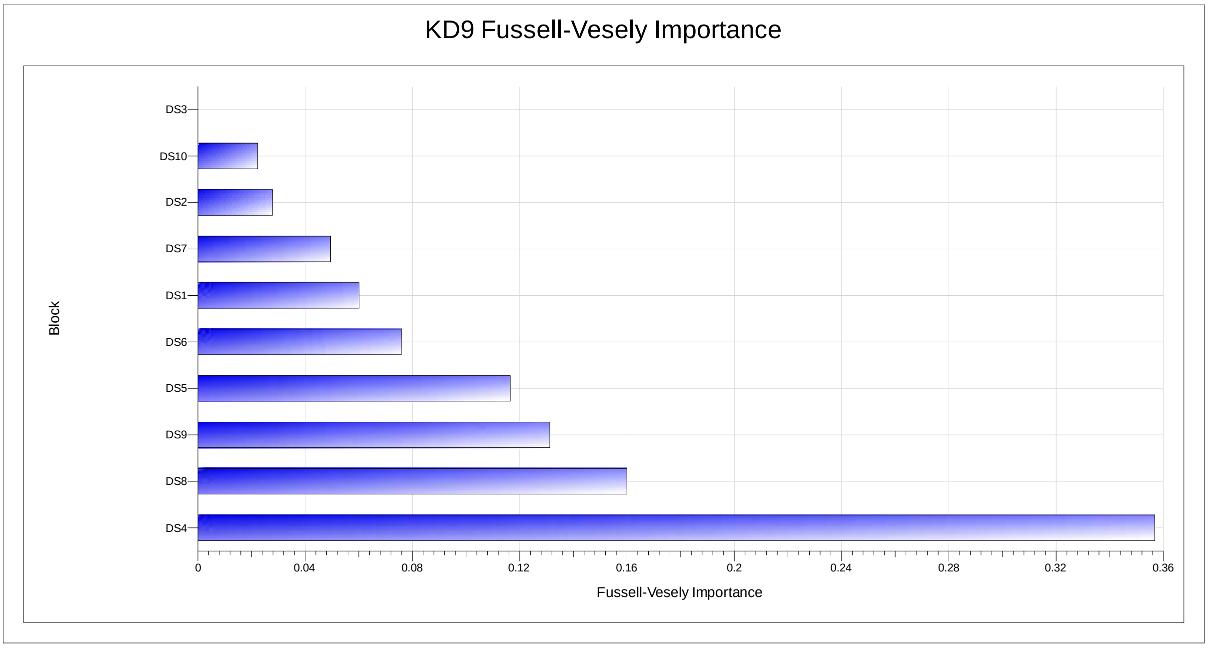

Figure D.27 Fussell-Vesely Importance of KD9 (Surface coal mine)

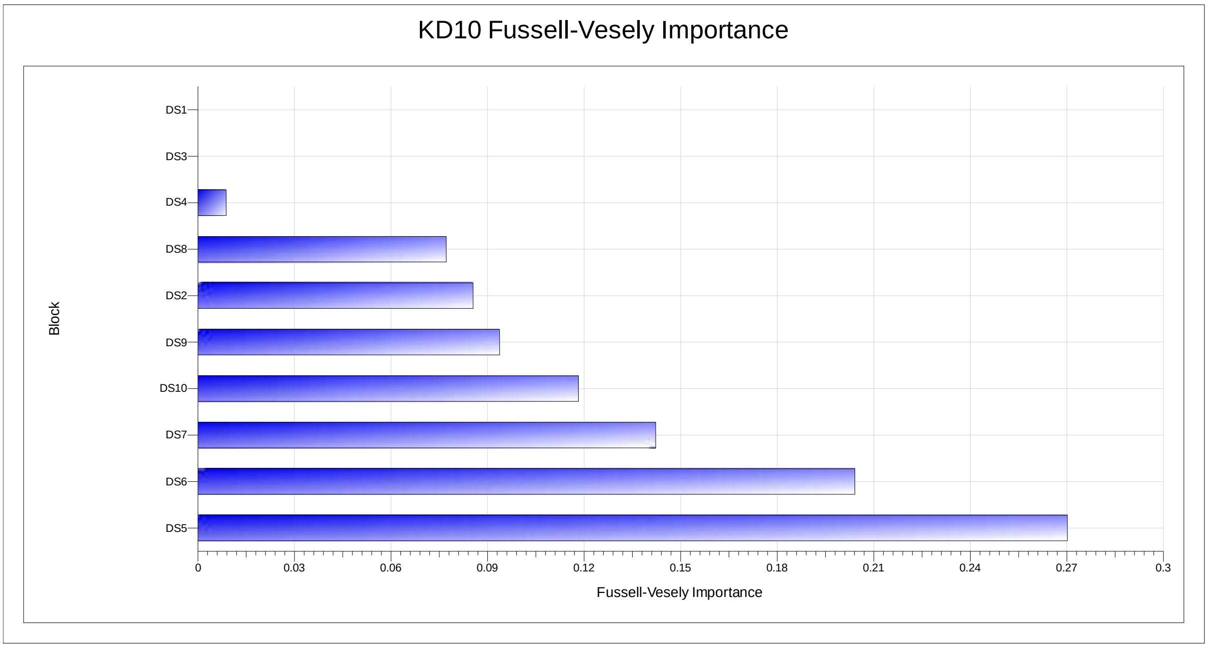

Figure D.28 Fussell - Vesely Importance of KD10 (Surface coal mine)

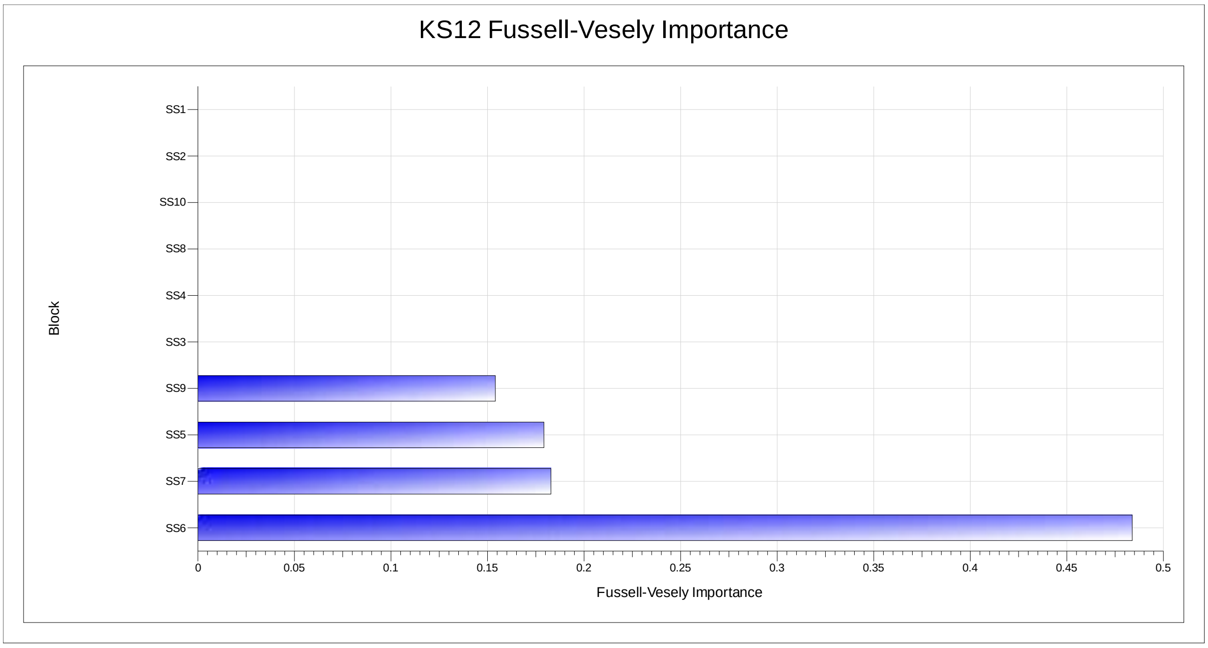

Figure D.29 Fussell-Vesely Importance of KS12 (Surface iron ore mine)

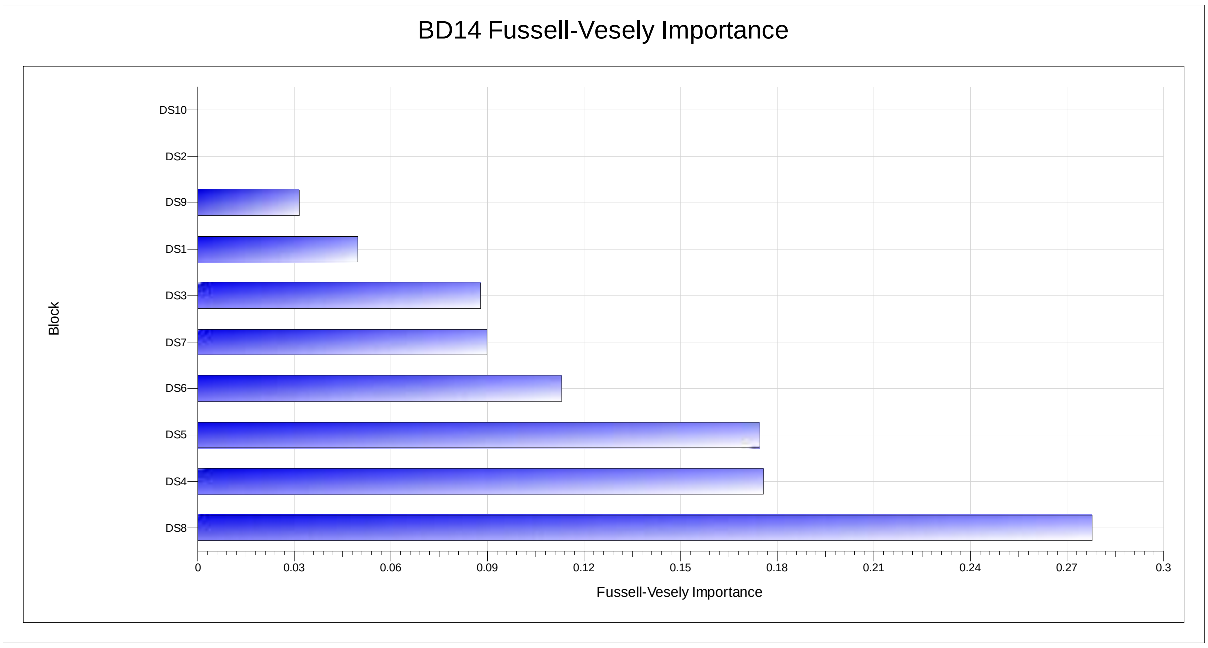

Figure D.30 Fussell-Vesely Importance of BD14 (Surface iron ore mine)

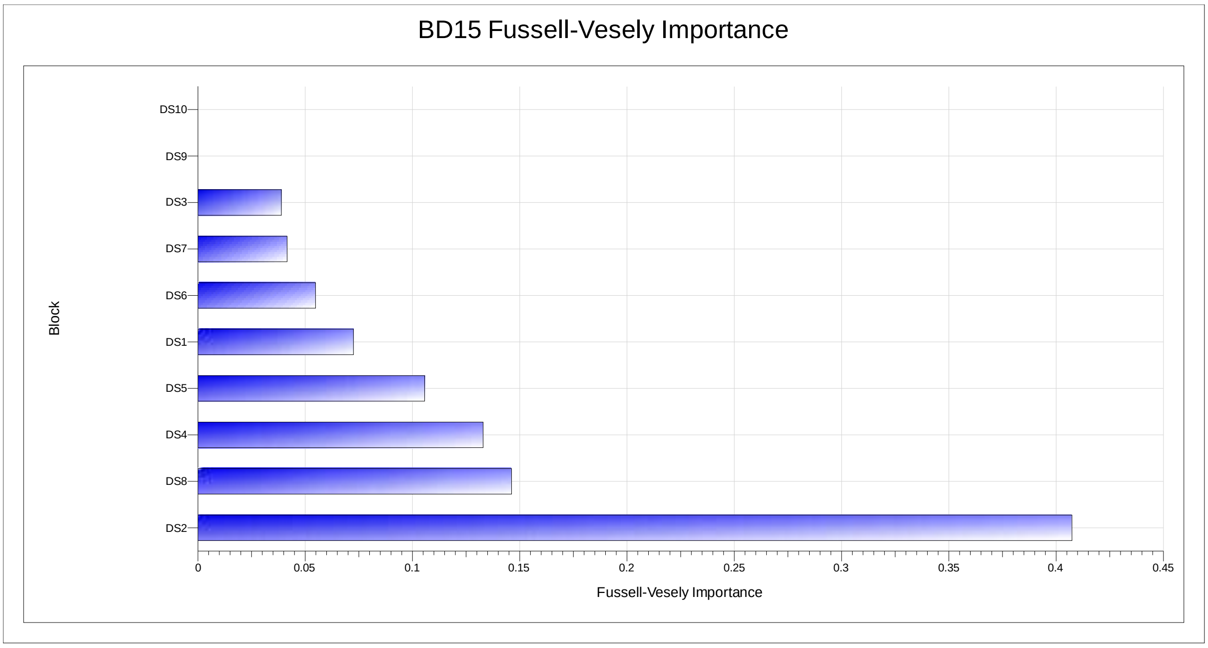

Figure D.31 Fussell-Vesely Importance of BD15 (Surface iron ore mine)

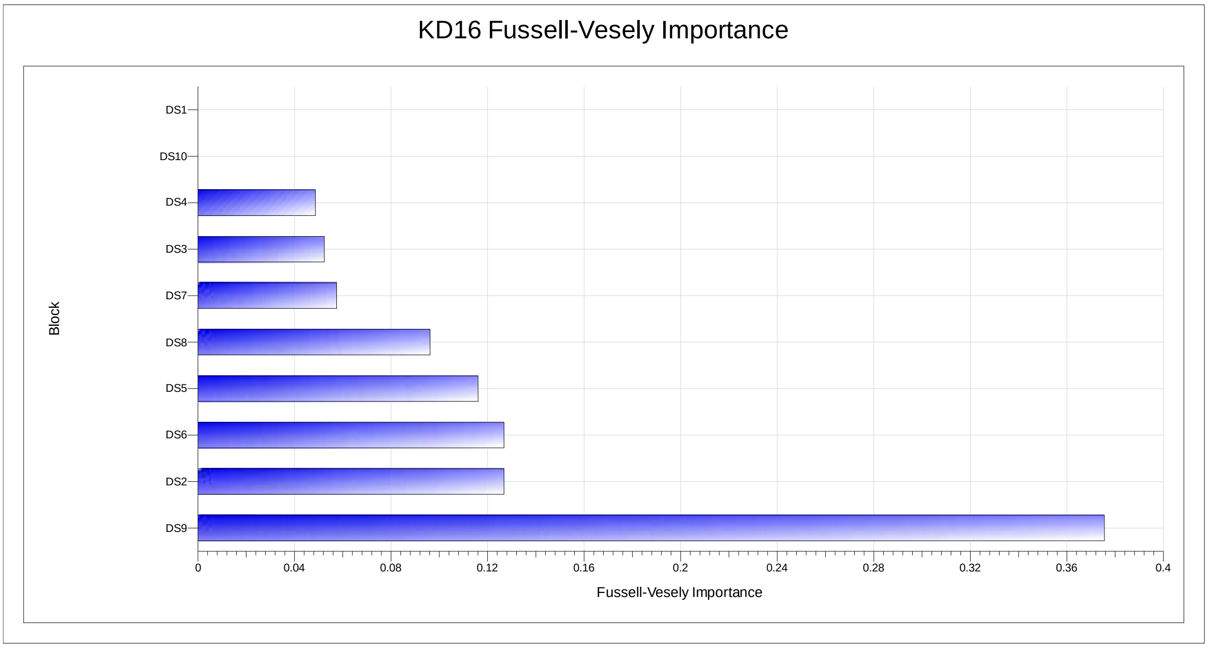

Figure D.32 Fussell-Vesely Importance of KD16 (Surface iron ore mine)

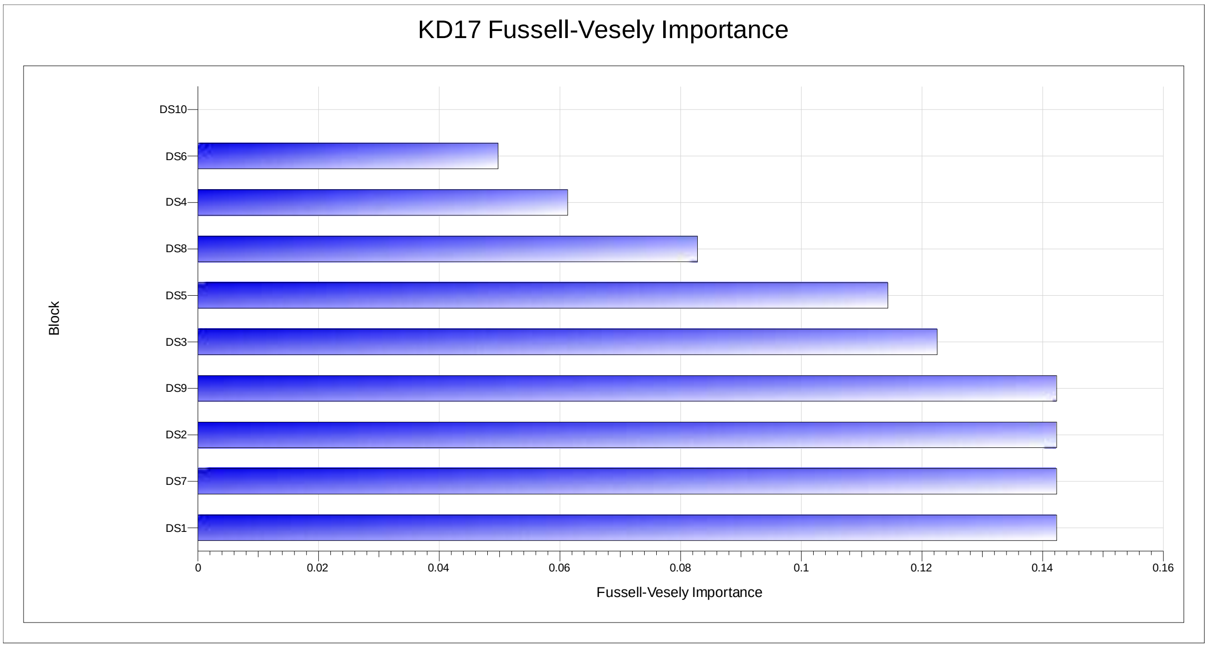

Figure D.34 Fussell-Vesely Importance of KD17 (Surface iron ore mine)

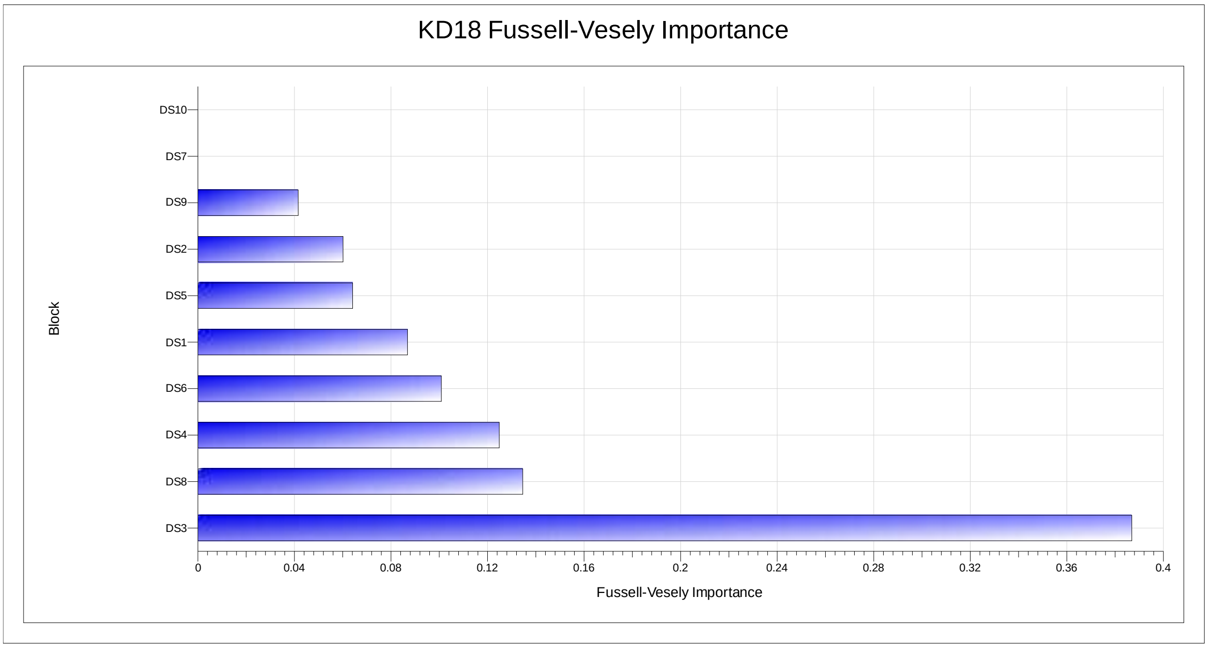

Figure D.35 Fussell-Vesely Importance of KD18 (Surface iron ore mine)

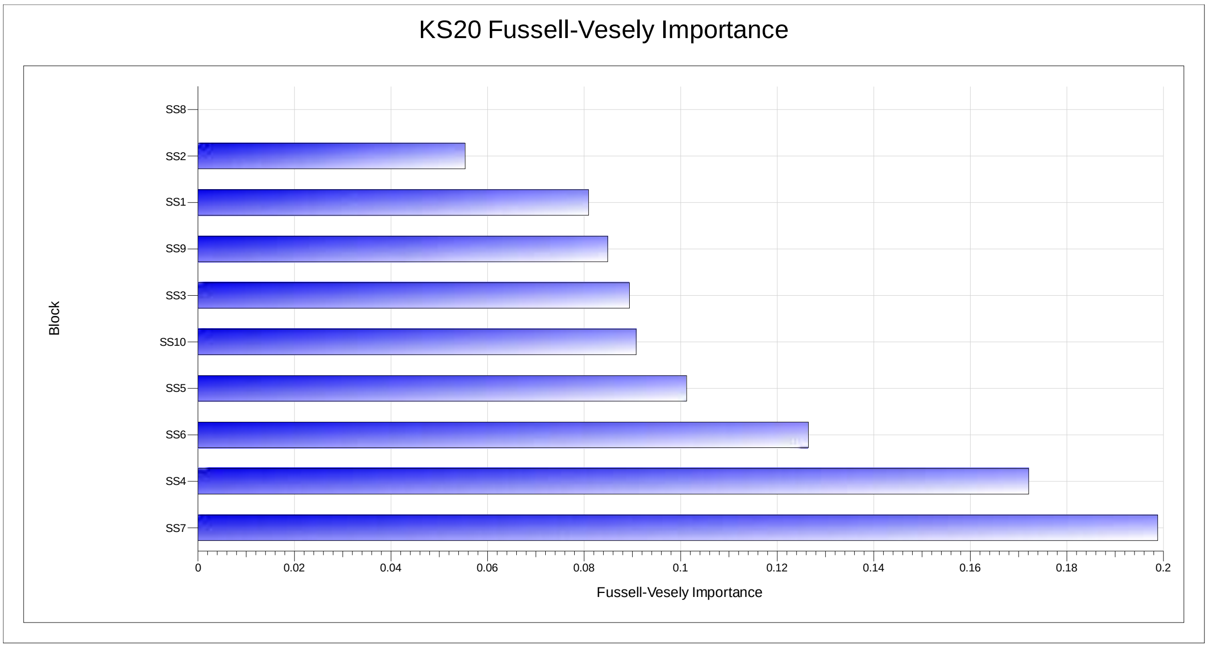

Figure D.36 Fussell-Vesely Importance of KS20 (Surface limestone mine)

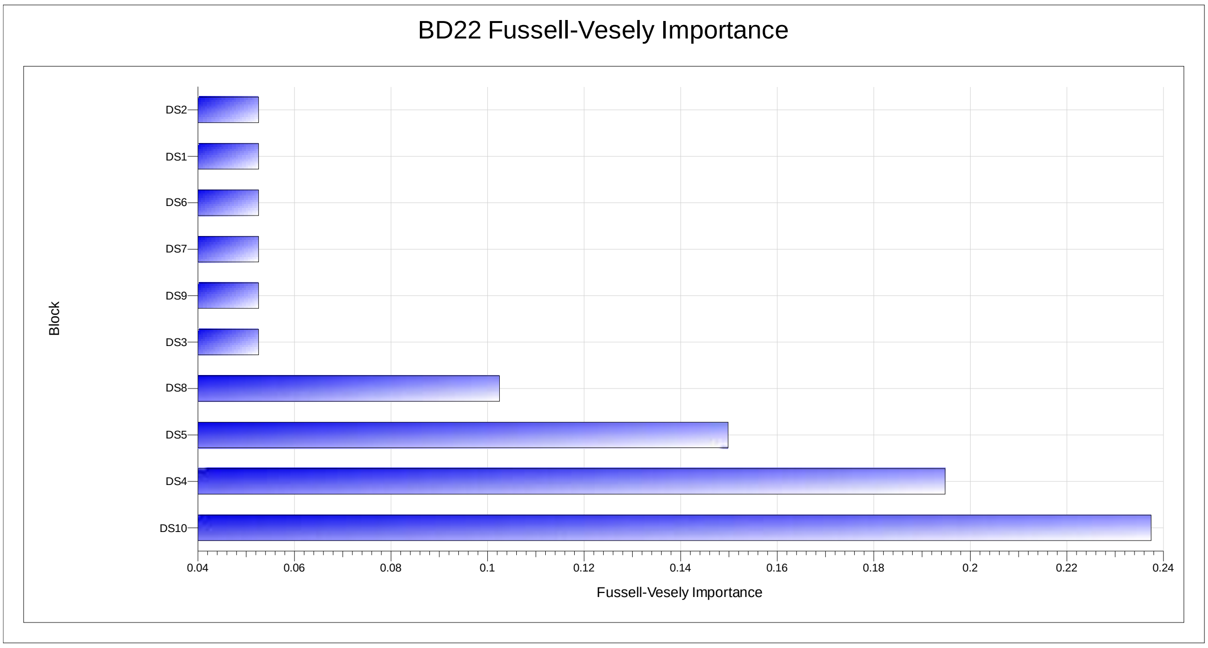

Figure D.37 Fussell-Vesely Importance of BD22 (Surface limestone mine)

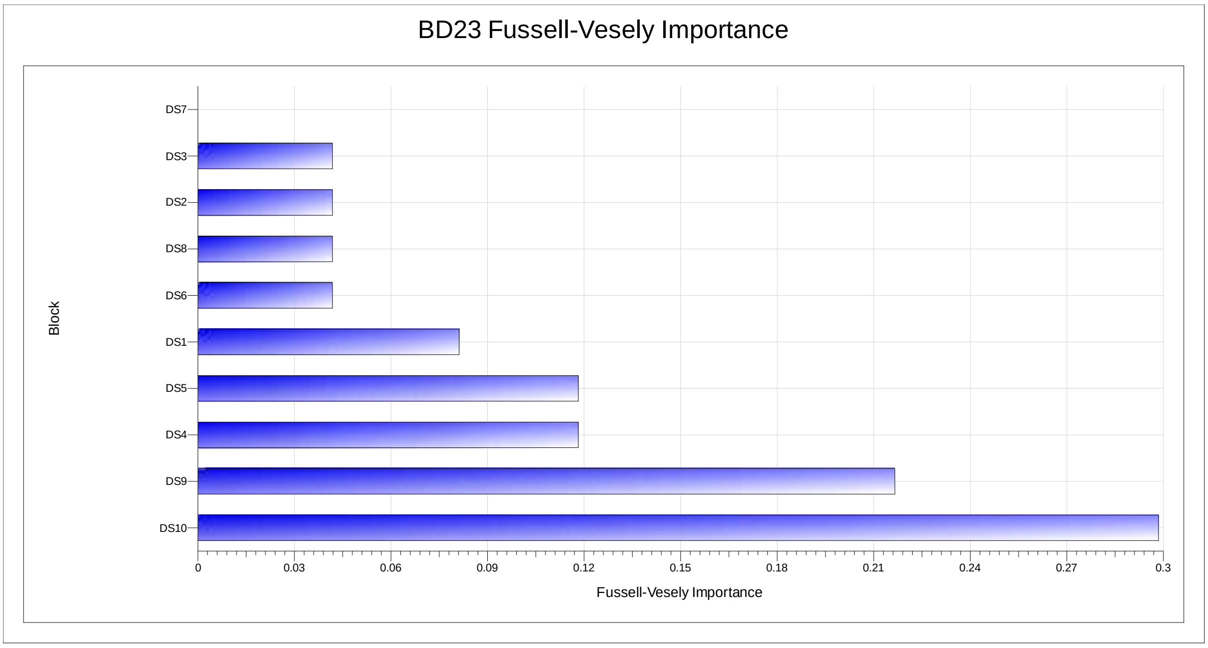

Figure D.38 Fussell-Vesely Importance of BD23 (Surface limestone mine)

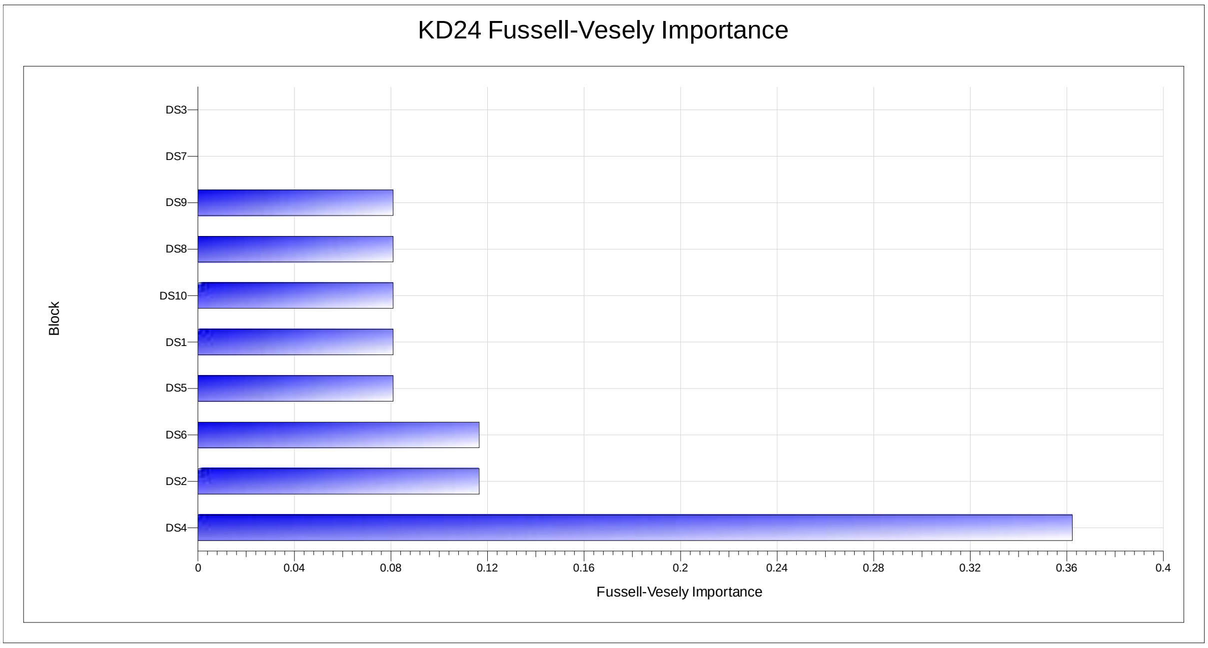

Figure D.39 Fussell-Vesely Importance of KD24 (Surface limestone mine)

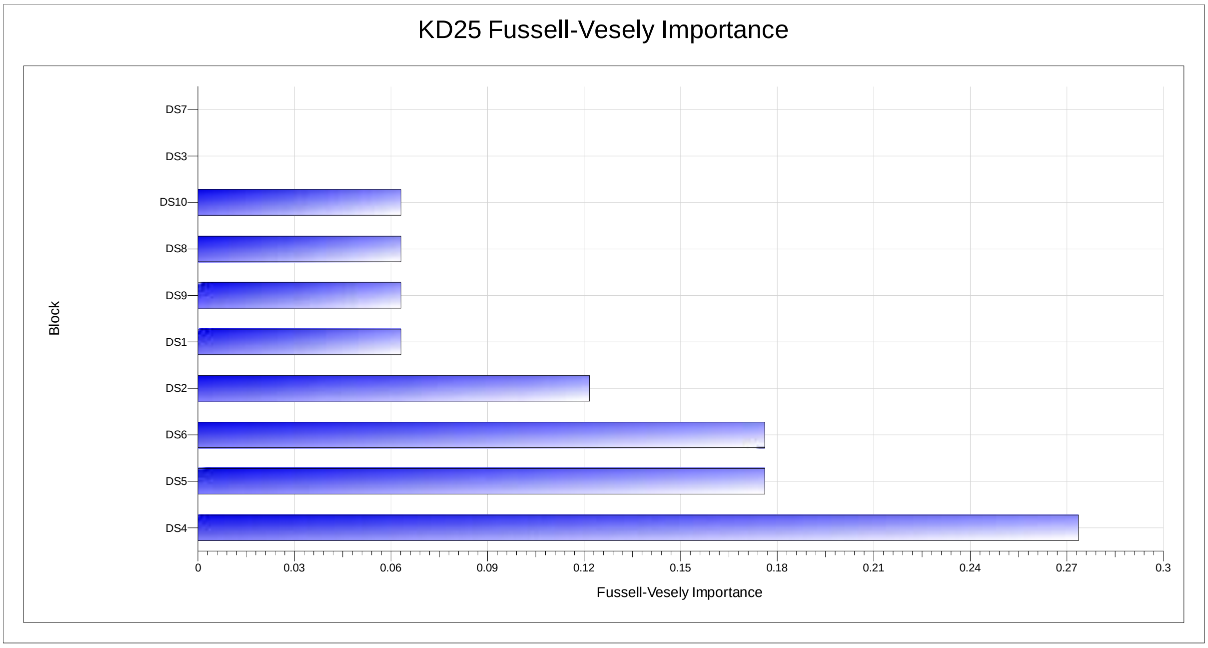

Figure D.40 Fussell-Vesely Importance of KD25 (Surface limestone mine)

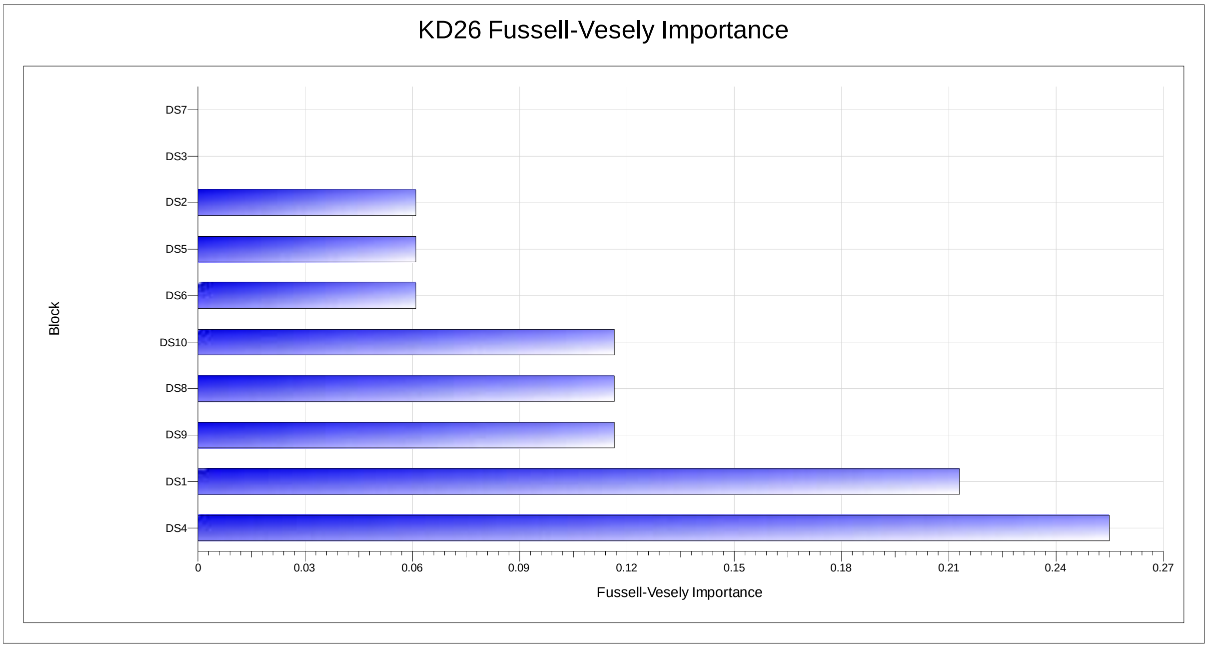

Figure D.41 Fussell-Vesely Importance of KD26 (Surface limestone mine)

D.3 Markov modeling of of shovel-dumper system

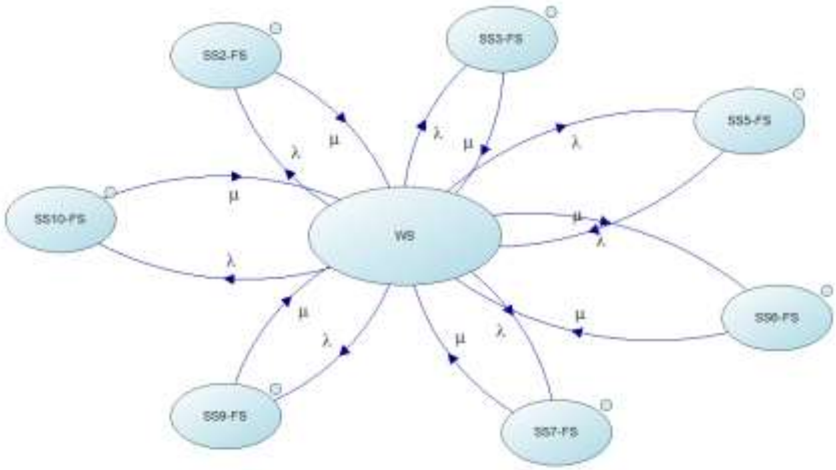

Figure D.42 Transition diagram of KS2 (Surface coal mine)

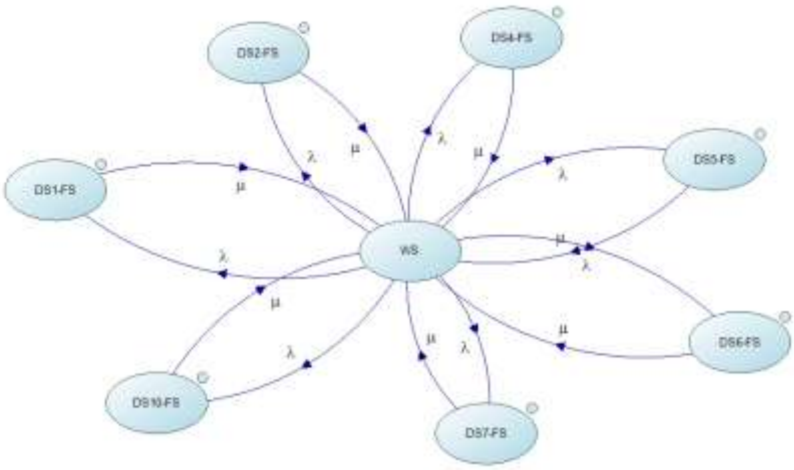

Figure D.43 Transition diagram of BD3 (Surface coal mine)

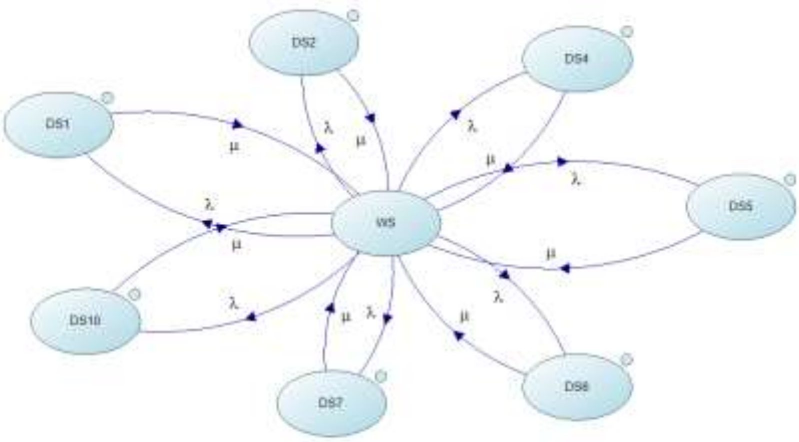

Figure D.44 Transition diagram of BD4 (Surface coal mine)

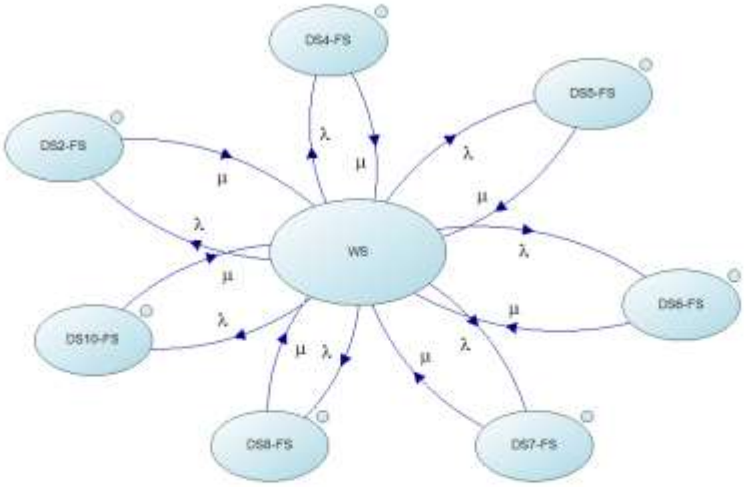

Figure D.45 Transition diagram of BD5 (Surface coal mine)

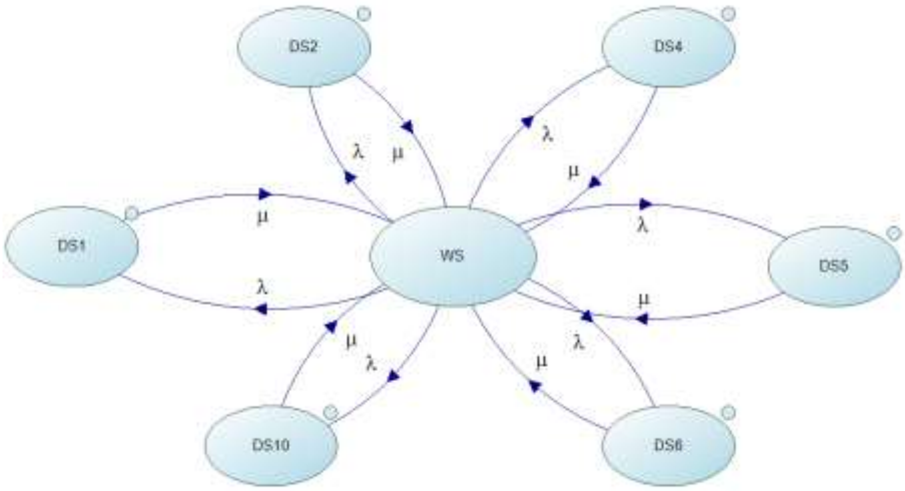

Figure D.46 Transition diagram of BD6 (Surface coal mine)

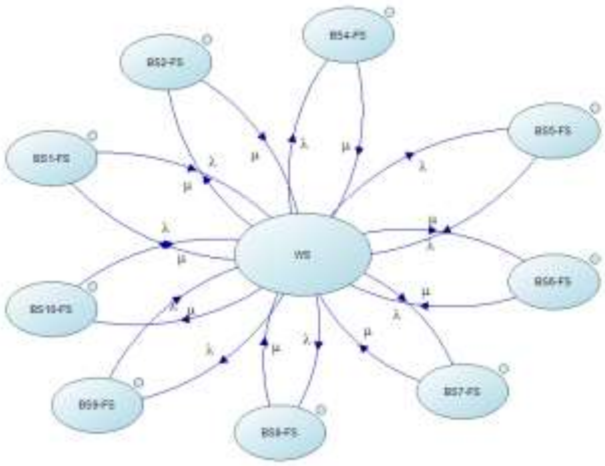

Figure D.47 Transition diagram of KD7 (Surface coal mine)

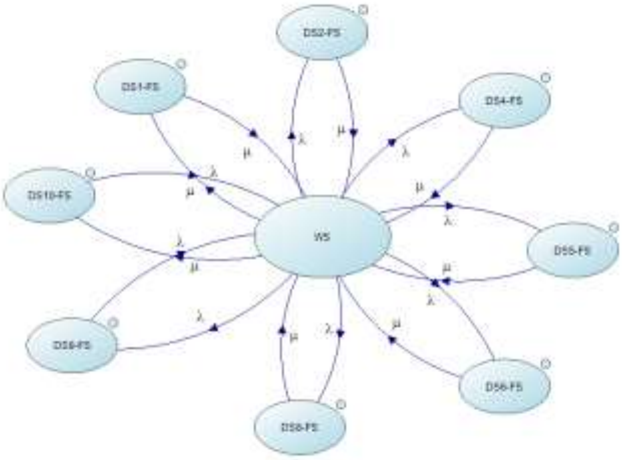

Figure D.48 Transition diagram of KD8 (Surface coal mine)

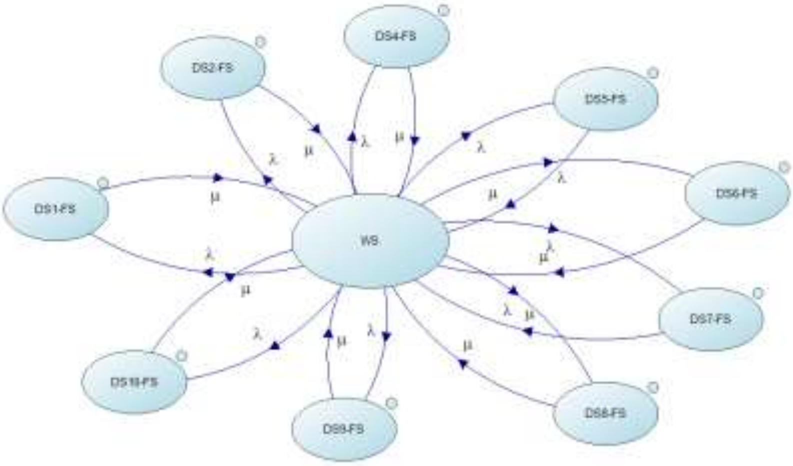

Figure D.49 Transition diagram of KD9 (Surface coal mine)

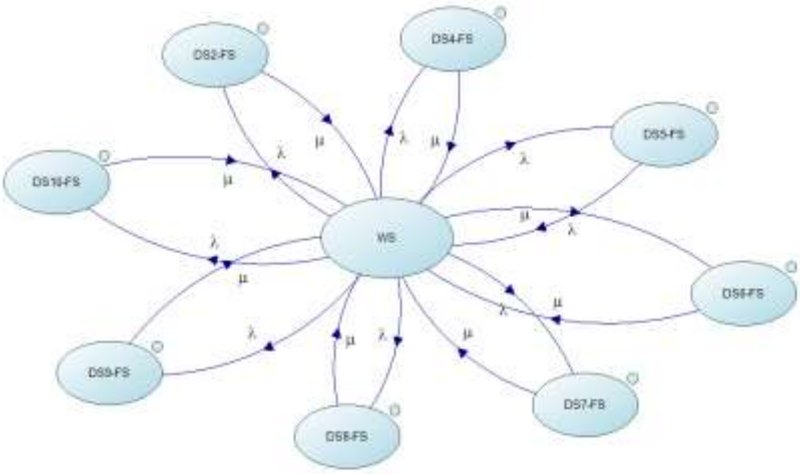

Figure D.50 Transition diagram of KD10 (Surface coal mine)

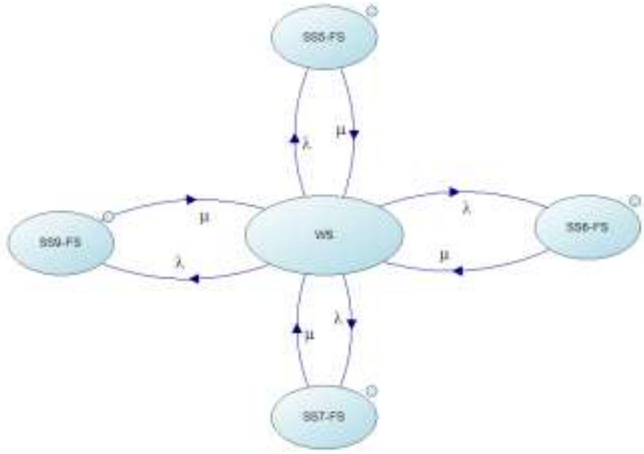

Figure D.51 Transition diagram of KS12 (Surface iron ore mine)

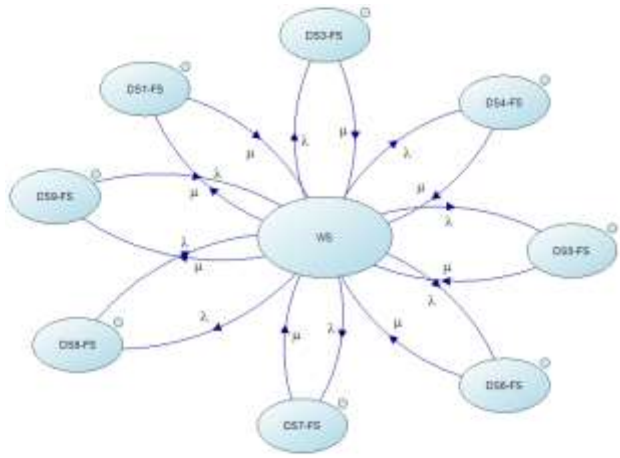

Figure D.52 Transition diagram of BD13 (Surface iron ore mine)

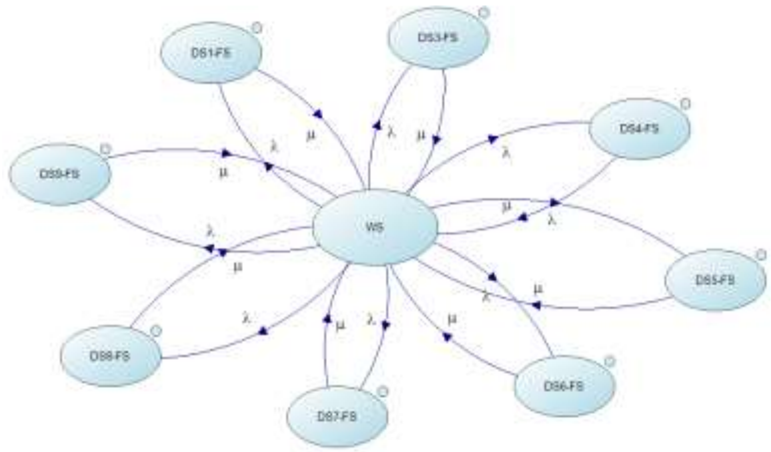

Figure D.53 Transition diagram of BD14 (Surface iron ore mine)

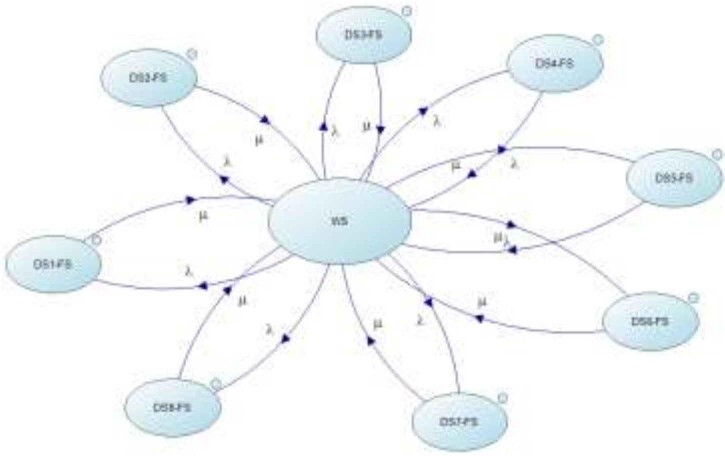

Figure D.54 Transition diagram of BD15 (Surface iron ore mine)

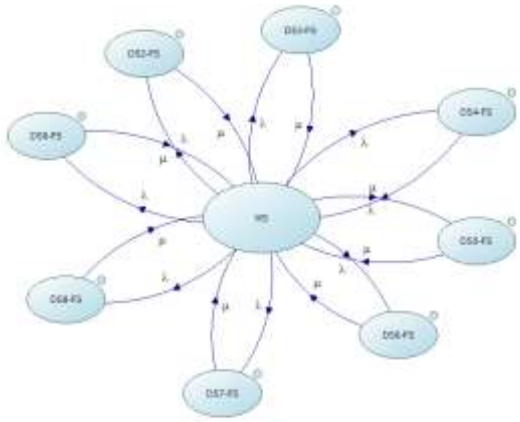

Figure D.55 Transition diagram of KD16 (Surface iron ore mine)

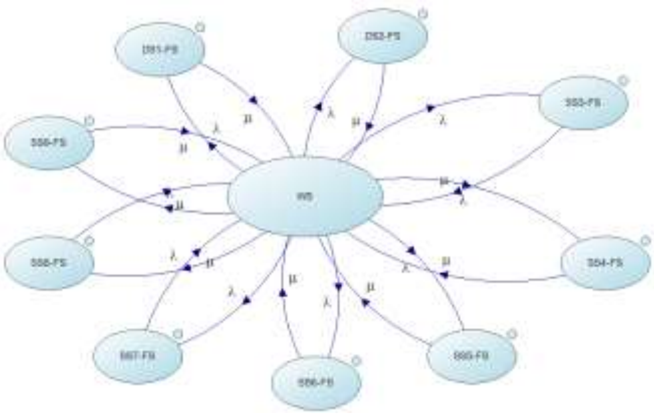

Figure D.56 Transition diagram of KD17 (Surface iron ore mine)

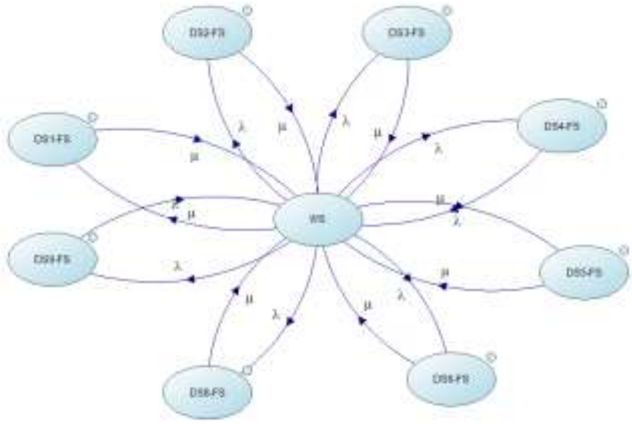

Figure D.57 Transition diagram of KD18 (Surface iron ore mine)

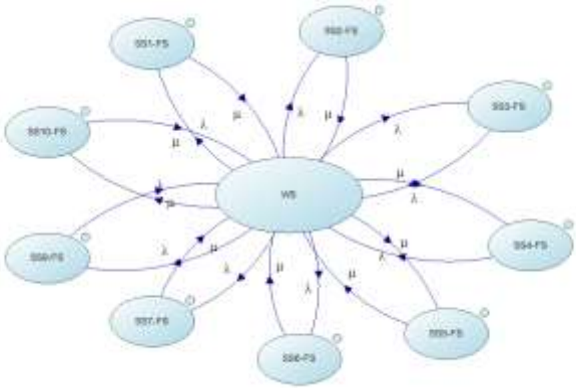

Figure D.58 Transition diagram of KS20 (Surface limestone mine)

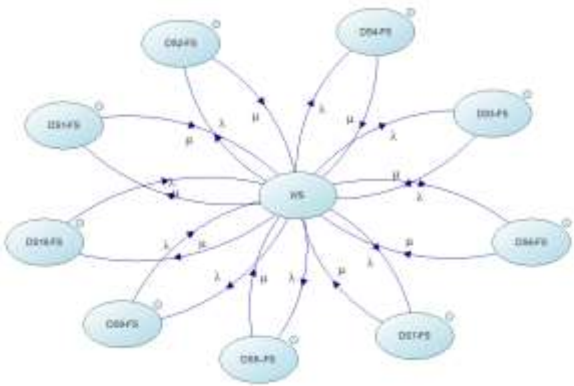

Figure D.59 Transition diagram of BD21 (Surface limestone mine)

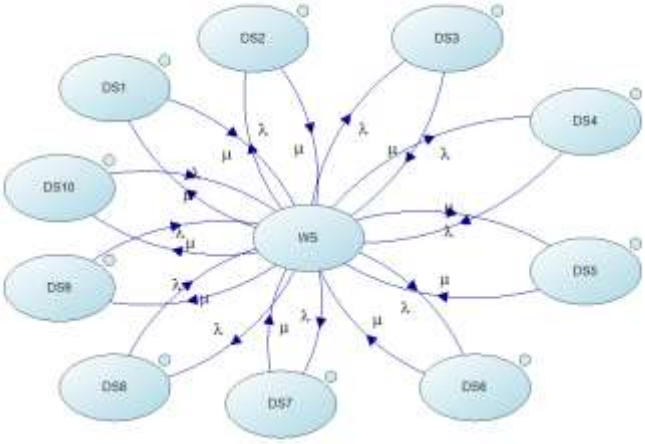

Figure D.60 Transition diagram of BD22 (Surface limestone mine)

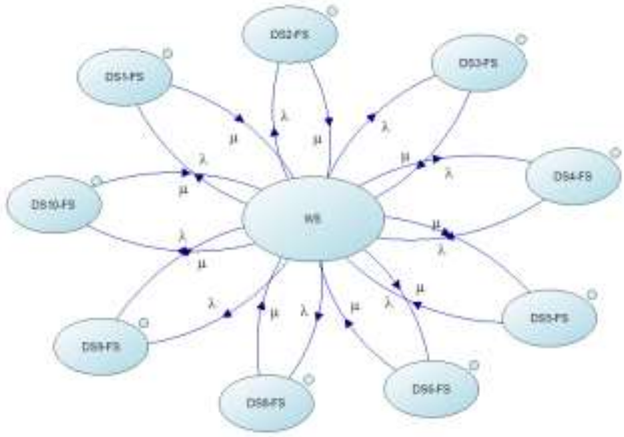

Figure D.61 Transition diagram of BD23 (Surface limestone mine)

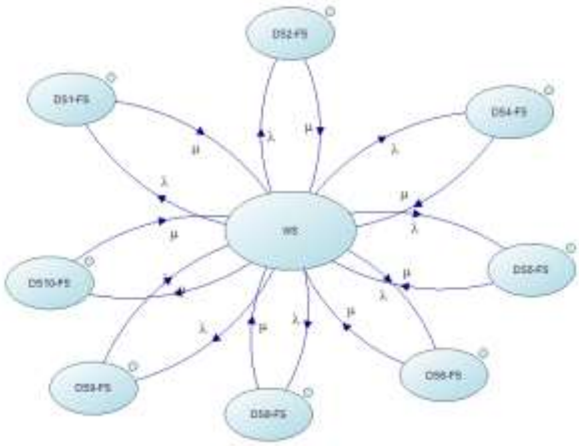

Figure D.62 Transition diagram of KD24 (Surface limestone mine)

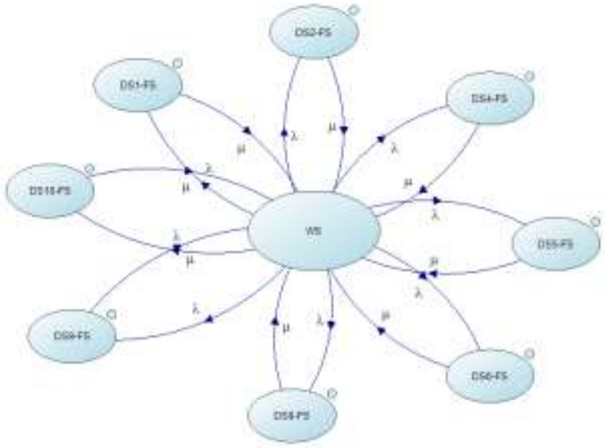

Figure D.63 Transition diagram of KD25 (Surface limestone mine)

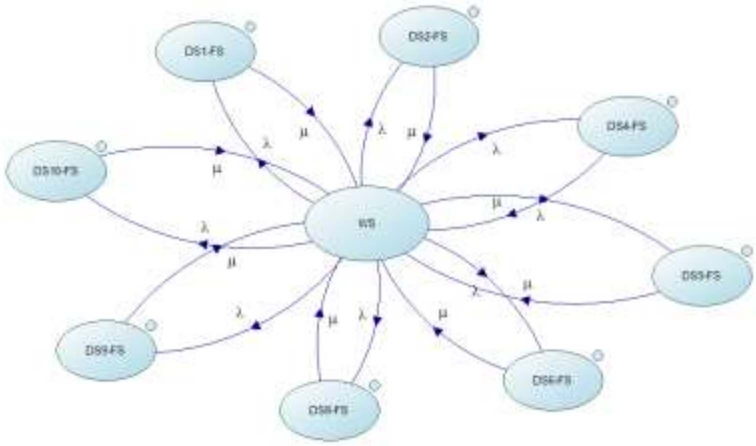

Figure D.64 Transition diagram of KD26 (Surface limestone mine)

LIST OF PUBLICATIONS

International Journals

1. **Harish Kumar N S**, R. P. Choudhary and Ch. S. N. Murthy (2020) "Reliability-based analysis of probability density function and failure rate of the shovel - dumper system in a surface coal mine". Modeling Earth Systems and Environment: Accepted for the Publication (Online View). (Scopus-Springer).
2. **Harish Kumar N S**, R. P. Choudhary and Ch. S. N. Murthy (2020) "Model based reliability analysis of shovel–dumper system's mechanical failures used in the surface coal mine: a case study." Journal of Safety and Reliability, 39 (3-4), 215-229. (Taylor and Francis).
3. **Harish Kumar N S**, R. P. Choudhary and Ch. S. N. Murthy (2019) "Evolution of the probability distribution function of shovel–dumper combination in open cast limestone mine using RWB and ANN: a case study" in Modeling Earth Systems and Environment, 5(4), 1607-1613. (Scopus/Springer)
4. **Harish Kumar N S**, R. P. Choudhary and Ch. S. N. Murthy (2019) "Failure rate analysis of shovel and dumper in opencast limestone mine using RWB and ANN" in International Journal of Innovative Technology and Exploring Engineering, 8(5), 1025-1030, 2019. (Scopus)
5. **Harish Kumar N S**, R. P. Choudhary and Ch. S. N. Murthy (2019) "Reliability-based preventive maintainability analysis of shovel-dumper system in surface coal mine using ANN and Isograph Reliability Workbench" in Mathematical Modelling of Engineering Problems, 5(4), 373-378. (Scopus and H-Indexed)
6. **Harish Kumar N S,** R. P. Choudhary and Ch. S. N. Murthy (2018) "Methods of reliability prediction for heavy earth moving machinery in surface mine: a review" in Journal of Emerging Technologies and Innovative Research, 5(12), 366-370, 2018. (WOS)

International Conference with Proceeding's (Scopus/Springer)

1. **Harish Kumar N S**, R. P. Choudhary and Ch. S. N. Murthy, presented and published a research paper entitled "Evaluation of the probability distribution function of shovel-

dumper combination in opencast coal mine using ANN and RWB" in International Conference on Emerging Trend in Engineering, organized by Department of Mining Engineering, Osmania University, Hyderabad during 22nd-23rd March, 2019 and published in Learning and Analytics in Intelligent Systems Series, 2, 293-302, (2020). (Springer Book Series)

2. **Harish Kumar N S**, R. P. Choudhary and Ch. S. N. Murthy, presented and published a research paper entitled "Failure rate and reliability of the KOMATSU hydraulic excavator in surface limestone mine" in International Conference on Design, Material and Manufacture, organized by Department of Mechanical Engineering, NITK Surathkal during 29th-31th January 2018 and published in American Institute of Physics (AIP) Conference Proceedings, 1943, 1-9, (2018). (Scopus and H-Indexed).
3. **Harish Kumar N S**, R. P. Choudhary and Ch. S. N. Murthy, presented and published a research paper entitled "Reliability analysis of dumper in lime stone mine based on Weibull distribution" proceeding of 91st International Conference on Innovative Engineering Technologies (ICIET), organized by The Institute of Research Engineers and Scientists, Chicago, USA" during 22nd-23rd March, 2017 and published in World Research Library, 6-10, (2017). (World Research Library).

International and National Conferences

1. **Harish Kumar N S,** Ch. S. N. Murthy and R. P. Choudhary, B. M. Kunar, presented a research paper entitled "Mathematical modeling for reliability analysis of shovel-dumper system in surface mine using RBD", in National Conference on "Advance in Mining (AIM-2020)", Organized by CSIR-Central Institute of Mining and Fuel Center, Dhanbad held on 14th-15th February 2020.
2. R. P. Choudhary, Ch. S. N. Murthy and **Harish Kumar N S,** presented a research paper entitled "Evolutions of probability distribution function of shovel-dumper combination in surface limestone mine", in National Conference on Mine Environment Techniques, Equipment's and Challenges (METEC-2018), organized by Department of Mining Engineering, MBM Engineering College, JNV University, Jodhpur held on 15th-16th December 2018.

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10. Academic Qualifications	:	

Degree	Specialization	Year	College	University	%
M. Tech (Full Time)	Machine Design	2010-2012	Nagarjuna College of Engineering and Technology (NCET), Bangalore, Karnataka, India-562110.	Visveswaraiah Technological University, Belagavi, (VTU), Karnataka, India-590018	74%
B. E (Full Time)	Mechanical Engineering	2006-2010	Dr. T. Thimmaiah Institute of Technology (Dr.TTIT) (Formerly Golden Valley Institute of Technology-GVIT), KGF. Karnataka, India. 563120.	Visveswaraiah Technological University, Belagavi, (VTU), Karnataka, India-590018	66%

Work Experience:

1. Worked as an **Assistant Professor** in the Department of Mechanical Engineering, **R. L. Jalappa Institute of Technology, Doddaballapur, Bangalore Rural** affiliated to Visveswaraiah Technological University, Belagavi, during August 2012 - July 2014 (2 Years).
2. Worked as an **Assistant Professor** in the Department of Mechanical Engineering, **REVA University, Bangalore,** one of the esteemed Deemed Universities, during August 2014 – December 2015 (1 Year, 5 Months).