Performance Modeling and Behavior Analysis of Coal Handling System of A Thermal Power Plant

Sorabh Gupta *, P.C. Tewari **, Avadhesh Kumar Sharma ***

Abstract

The present paper discusses the performance modeling and behavior analysis of a Coal Handling System of a thermal power plant using the concept of the performance analysis. A coal handling system ensures proper supply of coal for sound functioning of a thermal power plant. In the present paper, the coal handling system consists of two subsystems i.e. wagon tippler 'W' and conveyor 'C'. The behavior analysis of the coal handling system has been done with the help of performance modeling using a probabilistic approach. A transition diagram has been drawn and a set of differential equations have been generated. Based on these equations, the steady state probabilities are determined. Besides, some decision matrices are also developed, which provide various performance levels for different combinations of failure and repair rates of all subsystems. Based upon various performance values obtained in decision matrices and the plots of failure rates / repair rates of various subsystems, performance of each subsystem is analyzed and then maintenance decisions are made for all subsystems. This maintenance model helps in comparative evaluation of alternative maintenance strategies.

Key words: Performance analysis; steady state probabilities; decision matrices.

Associate Professor, Mech. Engg., HCTM, Kaithal (Haryana), India

e mail: sorabh_gupta123@rediffmail.com, 099960 21544

***Assistant Professor, Mech. Engg., NIT, Kurukshetra (Haryana), India,*

e mail: pctewari1@rediffmail.com

*** *Department of Mech. Engg.., D.C.R. Univ. of Sc.&Tech., Murthal, Sonipat (Haryana), India*

1. Introduction

In a coal fired thermal power plant, the chemical energy stored in coal, is converted successively to thermal energy, then to mechanical energy and, finally to electrical energy for continuous use and distribution across a wide geographic area. Coal is delivered by mass transport systems such as trucks, railways, barges or colliers. A typical large coal train called a "unit train" is about two kilometers long, contains 100 cars with 100 tons of coal in each car, for a total load of 10,000 tons. Modern unloaders use rotary dump devices, which eliminate problems with coal freezing in the bottom dump cars.

In India, coal is supplied to thermal power plant by railways. The railway wagons come in groups of 40 or 45 and for unloading purpose they are stationed on the wagon tippler lines. The wagons are unloaded into underground hoppers with the help of the wagon-tipplers. Wagon-tipplers are able to unload 750 tones per hour which is equal to the capacity of the conveyor system. The coal which is unloaded by the wagon tipplers is collected in two underground hoppers. From the underground hoppers the coal is transferred to either of the two conveyors by means of vibrating feeders. A typical feeder is 1220mm x 1520 mm long. It is of suspension mounting type with an electromagnetic vibrating drive. Dust suspension equipment is provided to suppress the coal dust created during the unloading of coal. There are two conveyors and failure of one leads to convey on other and the system does not stop working. From the conveyors the coal is again transferred to the next conveyor system. Again failure of one leads to convey on other, which supplies the coal to the crusher house. In the crusher house the size of coal pieces is reduced. If a situation arises where coal bunkers are full, then coal is crushed and stacked with the help of stacker re-claimers. If the crusher is not available, the uncrushed coal is stacked in the form of circular pile. At a particular moment when the coal bunkers are empty, the coal can be reclaimed with the help of the stacker. The aim of layout of coal handling plant is to provide maximum flexibility and to ensure high reliability of the plant. Thus the coal handling system is the main and most important part of a thermal plant.

2. System Description

The coal handling system consists of two sub-systems: wagon tippler (W) and conveyer (C) in series and each sub-system has one stand-by unit.

(1) The wagon tippler 'W' has two units in parallel. Failure of any unit, forces the stand-by unit to start. Complete failure of the system occurs when the stand-by unit of the wagon tippler also fails.

(2) The conveyor 'C' consists of two units, failure of the first unit forces the stand-by unit to run. Complete failure of the system occurs when the stand-by unit of conveyor also fails.

The transition diagram of coal handling system is as shown in figure 1 below.

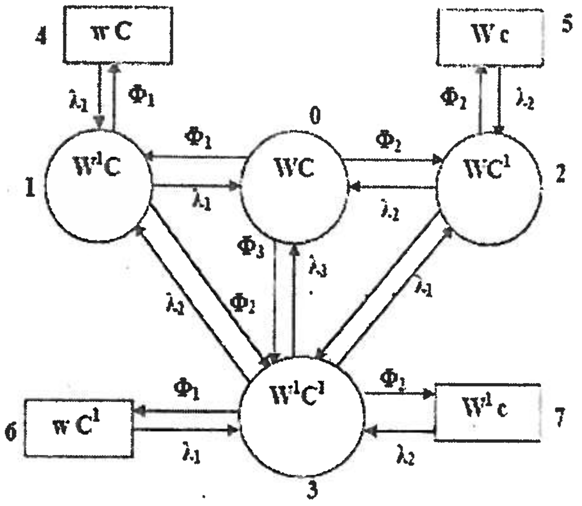


Figure No. 1: Transition diagram of coal handling system.

3. Notations

The symbols and notations associated with the transition diagram are as follows:

1. Indicates the system in operating condition.
2. Indicates the system in breakdown condition
3. W,C Indicate that the subsystems are working at full capacity.
4. W^1C^1 Indicate that stand-by units of the sub-systems are in operating state.
5. wc Indicates that both subsystems are in failed state due to failure of stand-by unit also.
6. Φ_1 Failure rate of sub-system W (Wagon Tippler).
7. Φ_2 Failure rate of sub-system C (Conveyor).
8. Φ_3 Failure rate of both sub-systems simultaneously.

9. λ_1 Repair rate of sub-system A.

10. λ_2 Repair rate of sub-system B.

11. λ_3 Repair rate of both sub-system simultaneously.

12. d/dt Indicates derivative w.r.t 't'.

13. P_0 (t) Denotes the probability that at time' t' all units are working.

14. P_1(t) Denotes the probability that at time 't' the system is working at full capacity with stand by unit of W.

15. P_2 (t) Denotes the probability that at time't' the system is working at full capacity with stand-by unit of C.

16. P_3 (t) Denotes the probability that at time 't' the system is working at full capacity with stand-by units of W & C simultaneously.

17. P_4 (t) Denotes the probability that at time 't' the system is in failed state due to failure of stand-by unit of W and sub-system C is working on original unit.

18. P_5 (t) Denotes the probability that at time 't' the system is in failed state due to failure of stand-by unit of C and sub-system W is working on original unit.

19. P_6 (t) Denotes the probability that at time 't' the system is in failed state due to failure of stand-by unit of W and sub-system C is working on stand-by unit.

20. P_7 (t) Denotes the probability that at time 't' the system is in failed state due to failure of stand-by unit of C and sub-system W is working on stand-by unit.

4. Assumption

1 Failed subsystems are repaired immediately.

2 A repaired subsystem is as good as new, performance wise for a specified duration.

3 Failure and repair rates are constant and statistically independent.

4 The stand by units are of same nature and capacity as the original subsystem.

5 The process of repair begins soon after a subsystem fails.

5. Performance Modeling of Coal Handling System

The mathematical modeling is done using simple probabilistic considerations and differential equations are developed using Markov birth-death process. If the state of the system is probability based, then the model is a Markov probability model. The present reliability analysis is concerned with a discrete-state continuous-time model, is also called a Markov process. Markov model is defined by a set of probabilities p_{ij} where p_{ij} is the probability of transition from any state i to any state j. For example, the equipment transits from operable state (i) to failed state (j) with probability P_{ij}. One of the most important features of the Markov process is that the transition probability p_{ij}; depends only on states i and j and is completely independent of all past states except the last one, state i.

The objective here is to obtain an expression for the probability of n occurrences in time t. Let the probability of n occurrences in time t be denoted by $P_n(t)$, i.e.,

$$\text{Probability}(X=n, t) = P_n(t) \qquad (n=0,1,2,\ldots).$$

Then, $P_0(t)$ represents the probability of zero occurrences in time t. The probability of zero occurrences in time (t + ?t) is given by

$$P_0(t+?t) = (1 - \lambda t)\, P_0(t)$$

i.e the probability of zero occurrences in time (t + ?t) is equal to the probability of zero occurrences in time t multiplied by the probability of no occurrences in time ?t. The probability of no occurrences in time ?t is obviously given by (1 -λ ?t). The probability of one occurrence in time (t + ?t) is composed of two parts, namely, (a) probability of zero occurrences in time t multiplied by the probability of one occurrence in the interval ?t and (b) the probability of one occurrence in time t multiplied by the probability of no occurrences in the interval ?t. Thus,

$P_1(t+?t)=(\Phi ?t)P_0(t)+(1-\lambda ?t)P_1(t)$

Or $P_1(t+?t)=P_0(t)\Phi.?t+(P_1(t)-\lambda ?t P_1(t)$

Or $P_1(t+?t)-P_1(t)=?t[\Phi.P_0(t)-\lambda P_1(t)]$

Or $P_1(t+?t)-P_1(t)/?t=\Phi P_0(t)-\lambda P_1(t)$

Lt ?t æ 0

$d/dt\,P_1(t)=\Phi P_0(t)-\lambda P_1(t)$ Or $d/dt\,P_1(t)+\lambda P_1(t)=\Phi P_0(t)$

Or $[d/dt+\lambda]P_1(t)=\Phi P_0(t)$ (A)

Using the concept in equation (A), and various probability considerations give the following differential equations associated with the coal handling system and these equations are solved for determining the steady state performance of coal handling system.

$d/dt\,P_0t+P_0t[\Phi_1+\Phi_2+\Phi_3]=P_1(t)\lambda_1+P_2(t)\lambda_2+P_3(t)\lambda_3$ (1)

$d/dt\,P_1t+P_1t[\Phi_1+\Phi_2+\lambda_1]=P_3(t)\lambda_2+P_0(t)\Phi_1+P_4(t)\lambda_1$ (2)

$d/dt\,P_2t+P_2t[\Phi_1+\Phi_2+\lambda_2]=P_0(t)\Phi_2+P_5(t)\lambda_2+P_3(t)\lambda_1$ (3)

$d/dt\,P_3t+P_3t[\lambda_1+\lambda_2+\lambda_3+\Phi_1+\Phi_2]=P_1(t)\Phi_2+P_0(t)\Phi_3+P_2(t)\Phi_1+P_6(t)\lambda_1+P_7(t)\lambda_2$ (4)

$d/dt\,P_4t+P_4t[\lambda_1]=P_1(t)\Phi_1$ (5)

$d/dt\,P_5t+P_5t[\lambda_2]=P_2(t)\Phi_2$ (6)

$d/dt\,P_6t+P_6t[\lambda_1]=P_3(t)\Phi_1$ (7)

$d/dt\,P_7t+P_7t[\lambda_2]=P_3(t)\Phi_2$ (8)

With initial conditions at time t=0

$P_i(t)=1$ for i=0 and =0 for i Á 0

Solution of the equations

The steady state behavior of the system can be analyzed by setting tæÄ and d/dtæ 0; the limiting probabilities from equations (1) – (8) are:

$P_0[\Phi_1+\Phi_2+\Phi_3]=P_1\lambda_1+P_2\lambda_2+P_3\lambda_3$

$P_1[\Phi_1+\Phi_2+\lambda_1]=P_3\lambda_2+P_0\Phi_1+P_4\lambda_1$

$P_2[\Phi_1+\Phi_2+\lambda_2]=P_0\Phi_2+P_5\lambda_2+P_3\lambda_1$

$P_3[\lambda_1+\lambda_2+\lambda_3+\Phi_1+\Phi_2]=P_1\Phi_2+P_0\Phi_3+P_2\Phi_1+P_6\lambda_1+P_7\lambda_2$

$P_4[\lambda_1]=P_1\Phi_1$

$P_5[\lambda_2]=P_2\Phi_2$

$P_6[\lambda_1]=P_3\Phi_1$

$P_7[\lambda_2]=P_3\Phi_2$

Solving these equations recursively, we get

$P_1=(\Phi_1+\lambda_2.f).P_0/b$

$P_2=(\Phi_2+\lambda_1.f).P_0/a$

$P_3=f.P_0$

$P_4=\Phi_1(\Phi_1+\lambda_2.f).P_0/b.\lambda_1$

$P_5=\Phi_2(\Phi_2+\lambda_1.f).P_0/a.\lambda_2$

$P_6=\Phi_1.f.P_0/\lambda_1$

$P_7 = \Phi_2.f.P_0/\lambda_2$

Where $f = [\Phi_3 ab + \Phi_1\Phi_2 (a + b)] / [(\lambda_1 + \lambda_2 + \lambda_3)\, ab - a\lambda_2\Phi_2 - b\lambda_1\Phi_1]$

Using normalizing conditions:

$P_0 + P_1 + P_2 + P_3 + P_4 + P_5 + P_6 + P_7 = 1$ Or

$P_0 = 1 / [1 + (1 + \Phi_1/\lambda_1 + \Phi_2/\lambda_2)\, f + (\Phi_1 + \lambda_2.f)/b).(1 + \Phi_1/\lambda_1) + ((\Phi_2 + \lambda_1.f)/a).(1 + \Phi_2/\lambda_2)]$

Availability function A_0 is summation of probabilities of all working states:

Therefore, $A_0 = P_0 + P_1 + P_2 + P_3$, Putting values of P_0, P_1, P_2 and P_3

$A_0 = P_0 + P_0 [(\Phi_1 + \lambda_2 f)/b + (\Phi_2 + \lambda_1.f)/a + f]$
or

$A_0 = P_0 [1 + (\Phi_1 + \lambda_2 f)/b + (\Phi_2 + \lambda_1 f)/a + f]$
or

$A_0 = [1 + f + (\Phi_1 + \lambda_2 f)/b + (\Phi_2 + \lambda_1 f)/a] / [1 + (1 + \Phi_1/\lambda_1 + \Phi_2/\lambda_2)\, f + (\Phi_1 + \lambda_2 f)/b.\,(1 + \Phi_1/\lambda_1) + (\Phi_2 + \lambda_1 f)/a.\,(1 + \Phi_2/\lambda_2)]$ (9)

Where $a = \Phi_1 + \lambda_2$, $b = \lambda_1 + \Phi_2$ and $f = [\Phi_3 ab + \Phi_1\Phi_2 (a + b)] / [(\lambda_1 + \lambda_2 + \lambda_3)\, ab - a\lambda_2\Phi_2 - b\lambda_1\Phi_1]$

6. Behavior Analysis

From maintenance history sheet of coal handling system of thermal power plant and through the discussions with the plant personnel, appropriate failure and repair rates of both subsystems are taken and decision matrices (performance values) are prepared accordingly (Table 1 and 2) by putting these failure and repair rates values in expression (9) for P_0. The behavior analysis deals with the quantitative analysis of all the factors viz. courses of action and states of nature, which influence the maintenance decisions associated with the coal handling system of thermal power plant. These decision models are developed under the real decision making environment i.e. decision making under risk (probabilistic model) and used to implement the proper maintenance decisions for the coal handling system. Table 1and 2 represent the decision matrices for both subsystems of the coal handling system. These matrices simply reveal the various performance levels for different combinations of failure and repair rates/priorities. These performance values obtained in decision matrices for both subsystems are then plotted. Figures 2 to 5 represent the plots for the various subsystems of coal handling system, depicting the effect of failure /repair rate of both subsystems on coal handling system performance. On the basis of decision support system developed, we may select the best possible combinations $(\hat{o}, \lambda)$.

7. Results And Discussion

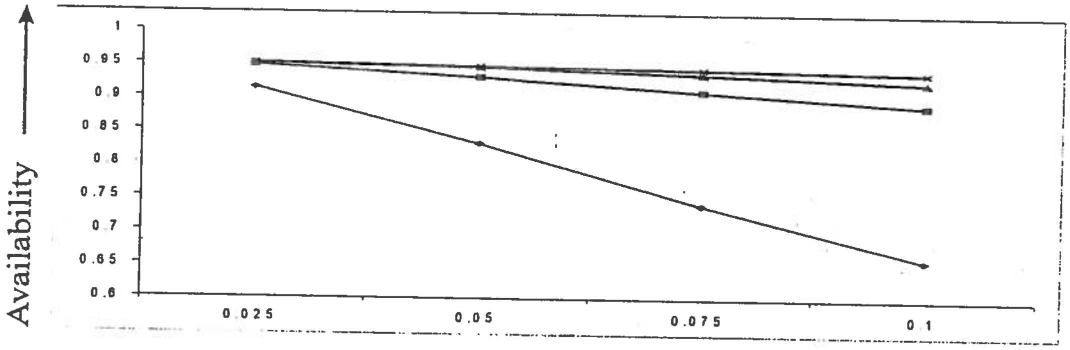
The resulting values as calculated from availability model expression (No.9) are shown in table no. 1 and 2, which are the availability of the subsystems 1 and 2 respectively and then these resulting values are plotted as shown in figure 2 to 5.

Table 1: Decision matrix of Wagon Tippler subsystem of coal handling system

Availability →

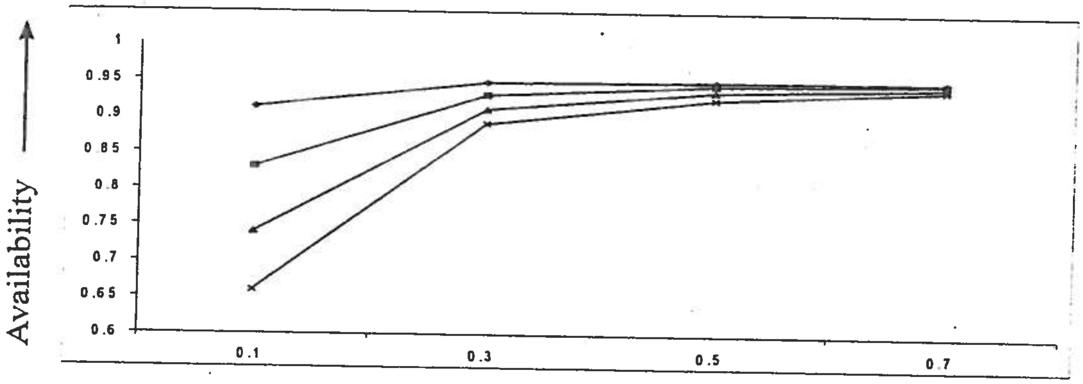
$\downarrow \Phi_1$ \ $\lambda_1 \rightarrow$	0.1	.3	.5	.7
0.025	0.913	0.947	0.95	0.951
0.05	0.83	0.93	0.945	0.948
0.075	0.74	0.91	0.936	0.944
0.1	0.66	0.89	0.925	0.94

Where Φ_1 is the failure rate and λ_1 is the repair rate of Wagon tippler subsystem of coal handling system



Effect of Failure Rate (Φ_1) →

Figure 2: The effect of failure rate of Wagon Tippler subsystem on coal handling system performance



Effect of Repair Rate (λ_1) →

Figure 3: The effect of repair rate of Wagon Tippler subsystem on coal handling system performance

Table 1 along with plot in figure 2 reveal the effect of failure rates and Table 1 along with plot in figure 3 reveal the effect of repair rates of wagon tippler subsystem on the performance of coal handling system. It is observed that for some known values of failure / repair rates of conveyor ($\Phi_2 = 0.3, \lambda_2=0.3$) and values of failure / repair rates of both subsystems simultaneously ($\hat{O}_3=.001$, $\lambda_3 =0.05$), as failure rate of wagon tippler increases from 0.025 (once in 40 hrs) to 0.1(once in 10 hrs), the subsystem performance decreases by approximately 25%. Similarly as repair rate of wagon tippler increases from 0.1 (once in 10 hrs) to 0.7 (once in 1.43 hrs), the subsystem performance increases by about 4 %.

Table 2: Decision matrix of Conveyor Subsystem of coal handling system

Availability →

λ_2 → ↓ Φ_2	0.1	.3	.5	.7
0.1	0.913	0.947	0.95	0.951
0.3	0.83	0.93	0.945	0.948
0.5	0.74	0.91	0.936	0.944
0.7	0.66	0.89	0.925	0.94

Where Φ_2 is the failure rate and λ_2 is the repair rate of conveyor subsystem of coal handling system

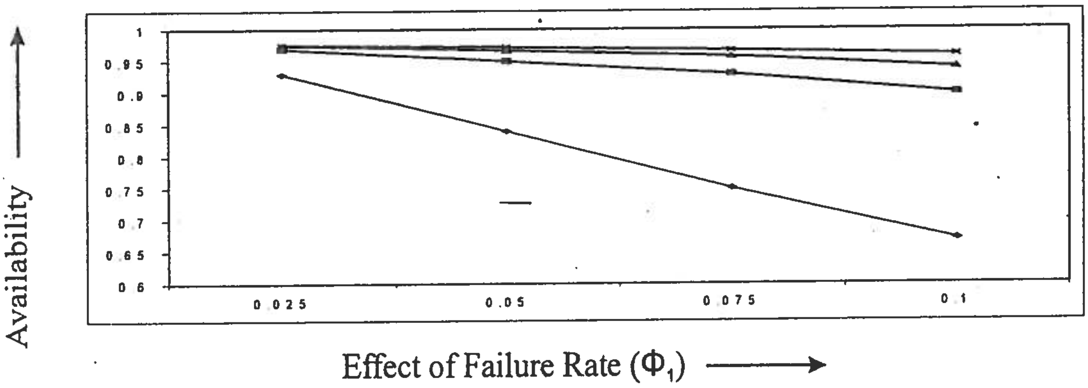


Figure 4: The effect of failure rate of Conveyor subsystem on coal handling system performance

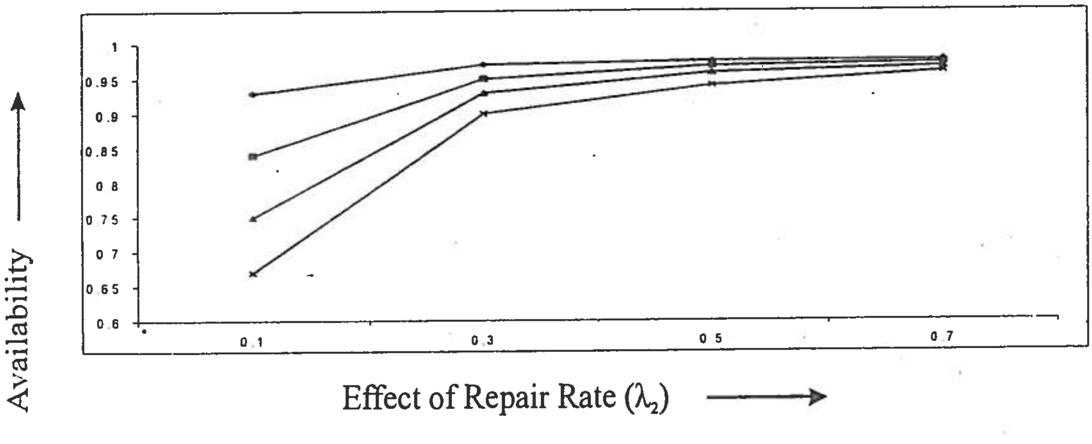


Figure 5: The effect of repair rate of Conveyor subsystem on coal handling system performance

Similarly, Table 2 along with plot in figure 4 highlight the effect of failure rates and Table 2 along with plot in figure 5 highlight the effect of repair rates of conveyor subsystem on the performance of coal handling system. It is observed that for some known values of failure / repair rates of wagon tippler ($\hat{o}_1$=0.05, λ_1=0.3) and values of failure / repair rates of both subsystems simultaneously ($\hat{o}_3$=.001, λ_3=0.05), as failure rate of conveyor increases from 0.025 (once in 40 hrs) to 0.1(once in 10 hrs), the subsystem performance decreases by about 26%, which is almost same as for wagon tippler subsystem. Similarly as repair rate of conveyor increases from 0.10 (once in 10 hrs) to 0.7 (once in 1.43 hrs), the subsystem performance increases by about 4 %, which is once again almost same as for wagon tippler subsystem.

8. Conclusions

The performance modeling and behavior analysis of coal handling system has been done with the help of mathematical modeling using probabilistic approach. The decision matrices are also developed. These matrices facilitate the maintenance decisions to be made at critical points where repair priority should be given to some particular subsystem of coal handling system. Decision matrix as given in tables (1 and 2) and plot in figures (2 to 5) clearly indicate that the both subsystems are of equal importance as far as maintenance aspect is concerned. So, both subsystems should be given equal importance as the effect of failure/repair rates of both subsystems on the subsystem performance is almost equal. Therefore, in the present paper, on the basis of failure/repair rates, the maintenance priority should be given either to wagon tippler or conveyor.

A large no. of failures occurs due to improper design and overstressing of components, which can be avoided by introducing the properly designed components of higher inbuilt performance. The system performance can be also being improved using redundancy technique. Here on introducing redundancy for a coal handling system in thermal power plant, it may concluded that performance improves by increasing repair and reducing failure rates for various sub-systems (subsystems), therefore, failure and repair rates of coal handling system should be optimized well to accomplish the goal of sufficiently high performance.

The main objective of performance modeling and behavior analysis of coal handling system is to decide about the relative repair priorities for both subsystems (wagon tippler and conveyor) of coal handling system. So findings of this paper will be highly beneficial to the plant management for the corrective and orderly execution of proper maintenance decisions and hence to enhance the performance of coal handling system of a thermal power plant.

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