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Reliability Measures Improvement and Sensitivity Analysis of a Coal Handling Unit for Thermal Power Plant

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ABSTRACT

The present paper investigates the reliability and sensitivity analysis of a coal handling unit of a thermal power plant using a probabilistic approach. Coal handling unit is the main block of a thermal power plant and it is necessary for a good function of a power plant that its power supply, which is dealt in coal handling unit, must function continuously without any obstacle. The configuration of the coal handling system consists of two subsystems connected in series, also each subsystem have two units in parallel configuration. Failure and repair rate of both the subsystems are taken constant. With the help of Laplace transforms and differential equations, the transition state probabilities, availability, reliability, MTTF, sensitivity analysis and cost-effectiveness of the system have been evaluated.

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1. INTRODUCTION

In real life, one can see many instances in which the system stops working due to improper power supply. To get set goal of production, it is necessary to keep our system failure free under the given operating conditions. High reliability of the system increases the efficiency of the production. In thermal power plants, there is maximum requirement of coal as fuel. Handling proper power supply in a power plant is a herculean task. If the power supply is not proper, then it may result in non-operational conditions and loss of production or affect the cost effectiveness of the system.

Many researchers have analyzed different types of power systems with different types of power failure. Castro and Cavalca [1] presented an availability optimization problem of an engineering system assembled in series configuration, using genetic algorithm. Kumar et al. [2-4] dealt with reliability, availability and operational behavior analysis for different systems in paper plant. Srinath [5] explained a Markov model to determine the availability expression for a simple system consisting of only one component. Arora and Kumar [6] discussed availability analysis of steam and power generation system in thermal power plant and discussed the availability analysis of a steam generation system consisting three subsystems A, B, D and a power generation system consisting of four subsystems E, F, G, H arranged in series, with three states viz., good, reduced and failed. Also, expressions for steady state availability and the MTBF (mean time between failures) are derived. Barabady and Kumar [7] analyzed availability importance measures in order to calculate the criticality of each component or subsystem from the availability point of view and also to demonstrate the application of such important measures for achieving optimal resource allocation to arrive at the best possible availability. Gupta and Gupta [8] discussed an electronic system consisting of two subsystems connected in series. One subsystem consisted of two identical units connected in parallel while the other subsystem had only one unit. The system was to be in any of the three states: good, degraded and failed. The system suffered two types of failures that were unit failure and failure due to critical human error. Khanduja et al. [9] dealt with the performance analysis of the screening unit in a paper plant using genetic algorithm. The screening unit in the paper plant had four main subsystems. Those

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subsystems were arranged in series and parallel configurations. Considering the exponential distribution for the probable failures and repairs, the mathematical formulation of the problem was done with Markov birth-death process. Gupta and Tewari [10] discussed the development of a performance model of power generation system of a thermal plant for performance evaluation using Markov technique and a probabilistic approach. The study covered two areas: development of a predictive model and evaluation of the performance with the help of developed models. The system of thermal plant under study consisted of four subsystems with three possible states: full working, reduced capacity working and failed. Failure and repair rates for all the subsystems were assumed to be constant. Khanduja et al. [11] studied the mathematical modeling and performance optimization of the paper making system in a paper plant using genetic algorithm. The paper making system had four main subsystems, arranged in series and parallel. Considering the exponential distribution for the probable failures and repairs, the mathematical formulation of the problem was done using probabilistic approach and differential equations developed based on Markov birth-death process. Furthermore, the authors Ram and Singh [12-17] analyzed and evaluated reliability measures for various engineering models under the concept of Gumbel-Hougaard family copula with different repair policies.

Gupta et al. [18] analyzed a thermal power plant to standby system and concluded that performance improved by increasing repair and reducing failure rates for the various subsystems, but they did not analyze the reliability, MTTF, cost-effectiveness and sensitivity of the system, which are the very important safety factors. So, considering the above literature review, in the present paper, the authors have analyzed the availability, reliability, MTTF and sensitivity analysis of coal handling unit of a thermal power plant. The coal handling unit consists of two subsystems namely Wagon Tripler and Conveyor which are connected in series configuration. The Wagon Tripler having two units in parallel. If one unit of Wagon Tripler fails, then other unit manages the work and if the second unit is also failed, then the Wagon Tripler is completely failed. Due to failure of Wagon Tripler, coal handling unit stops working. In the same manner Conveyor has two units in parallel, if one unit of Conveyor fails, then other unit manages the work and if second unit is also failed, then the Conveyor is completely failed and due to failure of Conveyor, coal handling unit stop working. In the research of Gupta et al. [18], a failed state repaired into degraded state, but in many situations, it is not possible for a thermal power plant. Here authors corrected this and a completely failed state is repaired into good state, and after that system works as good as new.

2. ASSUMPTIONS

The following assumptions are taken throughout the discussion of the model:

(i) Initially the system is in perfectly good state and all the components are perfect.

(ii) Failure and repair rate are taking to be constant of the system.

(iii) At every time sufficient repair facilities are available.

(iv) A repaired unit is as good as a new one.

(v) The system may work with reduced efficiency.

(vi) Consecutively both the units Wagon Tripler or Conveyor are not failed.

3. NOTATIONS

○	Indicates that the system is in good condition.
▱	Indicates that the system is in a degraded condition.
▭	Indicate that the system is failed.
$P_{00}(t)$	The probability that at time *t* system is working to full capacity.
$P_{01}(t)$	The probability that at time *t* system is working with one failed unit of the Conveyor.
$P_{10}(t)$	The probability that at time *t* system is working with one failed unit of Wagon Tripler.
$P_{11}(t)$	The probability that at time *t* system is working with one failed unit of Conveyor and one failed unit of Wagon Tripler.
$P_{21}(t)$	The probability that at time *t* system is failed due to failure of both units of Wagon Tripler.
$P_{12}(t)$	The probability that at time *t* system is failed due to failure of both units of the Conveyor.
ϕ_1	Unit repair rate of the Wagon Tripler.
ϕ_2	Unit repair rate of the Conveyor.
ϕ_3	Repair rate of both units. One from the Wagon Tripler and one of the Conveyor, if repair simultaneously.
λ_1	Unit failure rate of the Wagon Tripler.
λ_2	Unit failure rate of the Conveyor.
λ_3	Failure rate of both units. One from the Wagon Tripler and one of the Conveyor, if failed simultaneously.

4. STATE TRANSITION DIAGRAM OF MODEL

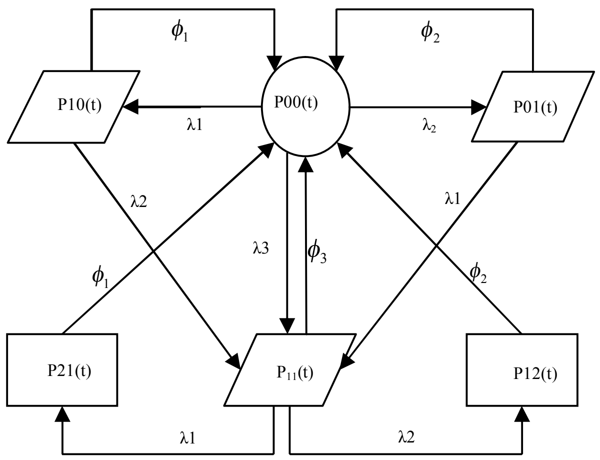

Figure 1. Transition state diagram

5. MATHEMATICAL FORMULATION AND SOLUTION OF THE MODEL

By the probability considerations and continuity arguments, we can obtain the following set of differential equations governing the present mathematical model:

$$\left[\frac{\partial}{\partial t}+\lambda_1+\lambda_2+\lambda_3\right]P_{00}(t)=\phi_1 P_{10}(t) +\phi_2 P_{01}(t)+\phi_3 P_{11}(t)+\int_0^\infty P_{21}(x,t)\phi_1 dx+\int_0^\infty P_{12}(x,t)\phi_2 dx \quad (1)$$

$$\left[\frac{\partial}{\partial t}+\phi_i+\lambda_j\right]P_{lm}(t)=\lambda_i P_{00}(t); \quad i=1,2;\ j=2,1; l=1,0; m=0,1 \quad (2)$$

$$\left[\frac{\partial}{\partial t}+\lambda_1+\lambda_2+\phi_3\right]P_{11}(t)=\lambda_1 P_{01}(t)+\lambda_2 P_{10}(t)+\lambda_3 P_{00}(t) \quad (3)$$

$$\left[\frac{\partial}{\partial t}+\frac{\partial}{\partial x}+\phi_i\right]P_{lm}(x,t)=0; \quad i=2,1; l=1,2; m=2,1 \quad (4)$$

Boundary conditions

$$P_{lm}(0,t)=\lambda_i P_{11}(t); l=2,1; m=1,2; i=1,2 \quad (5)$$

Initial condition

$P_0(0)=1$ and other state probabilities are zero at t = 0 (6)

Taking Laplace transformation of Equations (1-5) , we obtain:

$$\left[s+\lambda_1+\lambda_2+\lambda_3\right]\bar{P}_{00}(s)=1+\phi_1\bar{P}_{10}(s) +\phi_2\bar{P}_{01}(s)+\phi_3\bar{P}_{11}(s)+\int_0^\infty \bar{P}_{12}(x,s)\phi_1 dx+\int_0^\infty \bar{P}_{12}(x,s)\phi_2 dx \quad (7)$$

$$\left[s+\phi_i+\lambda_j\right]\bar{P}_{lm}(s)=\lambda_k\bar{P}_{00}(s); \quad i=1,2;\ j=2,1; l=1,0; m=0,1; k=1,2 \quad (8)$$

$$\left[s+\lambda_1+\lambda_2+\phi_3\right]\bar{P}_{11}(s)=\lambda_1\bar{P}_{01}(s)+\lambda_2\bar{P}_{10}(s)+\lambda_3\bar{P}_{00}(s) \quad (9)$$

$$\left[\frac{\partial}{\partial x}+s+\phi_i\right]\bar{P}_{lm}(x,s)=0; i=2,1; l=1,2; m=2,1 \quad (10)$$

$$\bar{P}_{lm}(0,s)=\lambda_k\bar{P}_{11}(s); l=2,1; m=1,2; k=1,2 \quad (11)$$

Solving Equations (7) to (11), with the help of Equation (6), one obtains:

$$\bar{P}_{00}(s)=\frac{U(s)}{M(s)N(s)-V(s)-W(s)-H(s)-X(s)-L(s)} \quad (12)$$

$$\bar{P}_{lm}(s)=\frac{\lambda_i\bar{P}_{00}(s)}{(s+\phi_j+\lambda_k)}; \quad l=1,0; m=0,1; i=1,2; j=1,2; k=2,1 \quad (13)$$

$$\bar{P}_{11}(s)=\frac{\bar{P}_{00}(s)}{(s+\lambda_1+\lambda_2+\phi_3)}\left[\lambda_3+\frac{\lambda_1\lambda_2}{(s+\phi_2+\lambda_1)}+\frac{\lambda_1\lambda_2}{(s+\phi_1+\lambda_2)}\right] \quad (14)$$

$$\bar{P}_{lm}(s)=\frac{\lambda_i[1-\overline{S_j}(s)]\bar{P}_{00}(s)}{(s+\lambda_k+\lambda_n+\phi_r)s}Y(s); \quad l=1,2; m=2,1; i=2,1; j=2,1; k=1; n=2; r=3 \quad (15)$$

where

$$H(s)=\frac{\lambda_1\lambda_2[\phi_3+\lambda_1\bar{S}_1(s)+\lambda_2\bar{S}_2(s)]}{(s+\phi_2+\lambda_1)},$$

$$\mathrm{L}(s)=\lambda_3[\phi_3+\lambda_1\bar{S}_1(s)+\lambda_2\bar{S}_2(s)],$$

$$\mathrm{M}(s)=[s+\lambda_1+\lambda_2+\lambda_3]$$

$$\mathrm{N}(s)=[s+\lambda_1+\lambda_2+\phi_3],$$

$$U(s)=s+\lambda_1+\lambda_2+\lambda_3$$

$$V(s)=\frac{\phi_1\lambda_1[s+\lambda_1+\lambda_2+\phi_3]}{(s+\phi_1+\lambda_1)}$$

$$W(s)=\frac{\phi_2\lambda_2[s+\lambda_1+\lambda_2+\phi_3]}{(s+\phi_2+\lambda_1)}$$

$$\mathrm{X}(s)=\frac{\lambda_1\lambda_2[\phi_3+\lambda_1\bar{S}_1(s)+\lambda_2\bar{S}_2(s)]}{(s+\phi_1+\lambda_2)}$$

$$Y(s)=[\lambda_3+\frac{\lambda_1\lambda_2}{(s+\phi_2+\lambda_1)}+\frac{\lambda_1\lambda_2}{(s+\phi_1+\lambda_2)}]$$

The Laplace transformation of the probabilities that the system is in up (i.e. either good or degraded state) and down (failed) state at any time is as follows:

$$\overline{P}_{up}(s) = \overline{P}_{00}(s) + \overline{P}_{10}(s) + \overline{P}_{01}(s) + \overline{P}_{11}(s) \tag{16}$$

$$\overline{P}_{down}(s) = \overline{P}_{12}(s) + \overline{P}_{21}(s) \tag{17}$$

6. PARTICULAR CASES AND NUMERICAL COMPUTATIONS

6. 1. Availability Analysis Taking the values of different parameters as $\lambda_1 = 0.15, \lambda_2 = 0.15, \lambda_3 = 0.10$, $\phi_1 = 1, \phi_2 = 1, \phi_3 = 1$ in Equation (16) and then taking inverse Laplace transform, we get the availability of the system:

$$P_{up}(t) = 0.3130434783e^{(-1.15t)} - 0.4615384615e^{(-1.3t)} + 0.9770664118 + 0.1714285714e^{(-1.4t)} \tag{18}$$

TABLE 1. Availability as a function of time

Time	Availability
0	1.000000
1	0.992677
2	0.984596
3	0.980232
4	0.978300
5	0.977525
6	0.977231
7	0.977124
8	0.977086
9	0.977073
10	0.977068

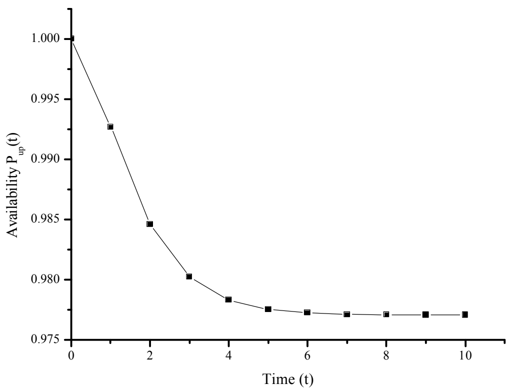

Figure 2. Availability as a function of time

6. 2. Reliability Analysis Taking all repairs equal to zero in Equation (16) and then taking the inverse Laplace transform, the reliability of the system is given as:

$$R(t) = \left(\begin{array}{l} [-(\lambda_2+\lambda_3)(\lambda_1+\lambda_3)(\lambda_1+\lambda_2)(\lambda_1\lambda_2-\lambda_3^2)t-\lambda_2\lambda_1^3 \\ +2\lambda_3^2\lambda_1\lambda_2-\lambda_1\lambda_2^3-\lambda_1^2\lambda_2^2+2\lambda_3^3\lambda_2 \\ +2\lambda_3^3\lambda_1-2\lambda_3\lambda_1\lambda_2^2-2\lambda_2\lambda_1^2\lambda_3+\lambda_3^4)]e^{[-(\lambda_1+\lambda_2+\lambda_3)t]} \end{array} \right) \Big/ (\lambda_1+\lambda_3)^2(\lambda_2+\lambda_3)^2 + \frac{\lambda_1(\lambda_1+\lambda_2)e^{(-\lambda_2 t)}}{(\lambda_1+\lambda_3)^2} + \frac{\lambda_2(\lambda_1+\lambda_2)e^{(-\lambda_1 t)}}{(\lambda_2+\lambda_3)^2} \tag{19}$$

Put $\lambda_1 = 0.01$, $\lambda_2 = 0.02$, $\lambda_3 = 0.03$, in Equation (20), we obtain:

$$R(t) = (0.0105t + 0.5725)e^{(-0.06t)} + 0.1875e^{(0.02t)} + 0.24e^{(-0.01t)} \tag{20}$$

Setting time unit t= 0 to 10 in Equation (19), one can obtain the Table 2 and Figure 3, which represent the reliability of the design system

6. 3. Mean Time to Failure (MTTF) Analysis Taking all repairs to zero for exponential distribution in Equation (16) as s tends to zero, one can obtain the mean time to failure (MTTF) of the system.

$$MTTF = \frac{(\lambda_1+\lambda_2)}{(\lambda_1+\lambda_2+\lambda_3)^2}[2 + \frac{\lambda_2}{\lambda_1} + \frac{\lambda_1}{\lambda_2} + \frac{\lambda_3}{(\lambda_1+\lambda_2}] \tag{21}$$

TABLE 2. Reliability as a function of time

Time	Reliability
0	1.000000
1	0.970447
2	0.941782
3	0.913990
4	0.887056
5	0.860963
6	0.835694
7	0.811231
8	0.787556
9	0.764649
10	0.742492

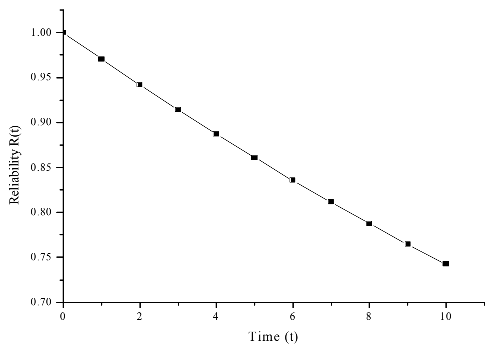

Figure 3. Reliability as a function of time

Setting $\lambda_2 = 0.02$, $\lambda_3 = 0.03$ and varying λ_1 from 0.01 to 0.09, then setting $\lambda_1 = 0.01$, $\lambda_3 = 0.03$ and varying λ_2 from 0.01 to 0.09, then setting $\lambda_1 = 0.01$, $\lambda_2 = 0.02$ and varying λ_3 from 0.01 to 0.09, in Equation (21), one can obtain Table 3.

6. 4. Sensitivity Analysis The sensitivity of the reliability by a demanding input factor is most regularly defined as the partial derivative of the reliability with respect to that factor. This measure then is used to estimate the outcome of factor changes on the model result without requiring a full model solution for each factor change. These input factors are mostly failure rates. In similar passion, one can define sensitivity of MTTF with respect to input factors.

6. 4. 1 Sensitivity of Reliability Here, authors first perform a sensitivity analysis for changes in reliability resulting from changes in the system parameters λ_1, λ_2 and λ_3 by differentiating Equation (19) with respect to failure rates λ_1, λ_2 and λ_3 respectively and by putting λ_1=0.01, λ_2=0.02, λ_3=0.03, get the values of $\frac{\partial R(t)}{\partial \lambda_1}, \frac{\partial R(t)}{\partial \lambda_2}, \frac{\partial R(t)}{\partial \lambda_3}$.

Now, taking t=0 to 10 units of time in the partial derivatives of reliability with respect to different failure rates, one can obtain the Table 4 and Figure 5, respectively.

6. 4. 2. Sensitivity of MTTF Sensitivity analysis for changes in MTTF resulting from changes in system parameters i.e. system failure rates $\lambda_1, \lambda_2, \lambda_3$. By differentiating Equation (21) with respect to failure rates λ_1, λ_2, λ_3 respectively, we get the values of $\frac{\partial(MTTF)}{\partial \lambda_1}, \frac{\partial(MTTF)}{\partial \lambda_2}, \frac{\partial(MTTF)}{\partial \lambda_3}$.

TABLE 3. MTTF as a function of failure rates

Variations in λ_1, λ_2, λ_3	MTTF with respect to failure rates λ_1	λ_2	λ_3
0.01	45.833333	44.000000	90.624999
0.02	38.775510	45.833333	62.000000
0.03	37.239583	49.659863	45.833333
0.04	37.037037	53.515625	35.714285
0.05	37.300000	57.037037	28.906250
0.06	37.741046	60.166666	24.074074
0.07	38.244047	62.927981	20.500000
0.08	38.757396	65.364583	17.768595
0.09	39.257369	67.521367	15.625000

TABLE 4. Sensitivity of reliability as a function of time

Time	$\frac{\partial R(t)}{\partial \lambda_1}$	$\frac{\partial R(t)}{\partial \lambda_2}$	$\frac{\partial R(t)}{\partial \lambda_3}$
0	0	0	0
1	0.00003018	0.00012688	-0.97030330
2	0.00021795	0.00096592	-1.88245056
3	0.00066119	0.00310258	-2.73834294
4	0.00140237	0.00699979	-3.53992833
5	0.00243797	0.01301357	-4.28918552
6	0.00372681	0.02140715	-4.98811039
7	0.00519739	0.0323634823	-5.63870382
8	0.00675431	0.04599648	-6.24296124
9	0.00828392	0.06236117	-6.80286337
10	0.00965909	0.08146244	-7.32036832

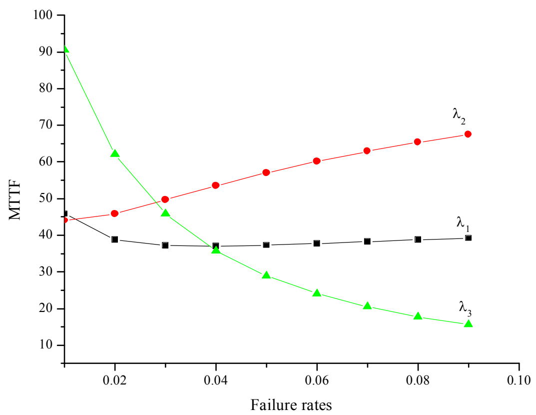

Figure 4. MTTF as a function of failure rates

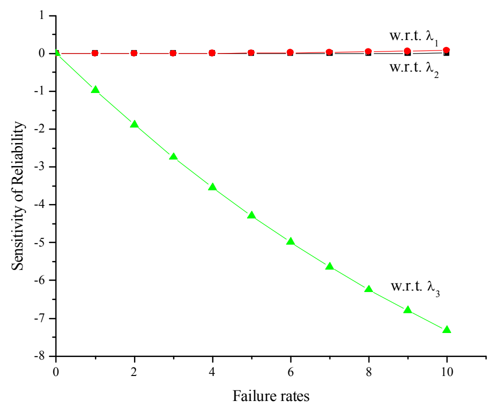

Figure 5. Sensitivity of Reliability as function of time

Varying the failure rates one by one respectively as 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08 and 0.09 in the partial derivatives of MTTF with respect to different failure rates, one can obtain the Table 5 and Figure 6, respectively.

6. 5. Expected Profit Let the service facility be always available, then expected profit during the interval [0, *t*] is given as:

$$E_p(t) = K_1\int_0^t P_{up}(t)dt - tK_2 \quad (22)$$

Using Equation (18) in Equation (22), expected profit for the same set of parameters is given as:

$$E_p(t) = K_1[0.3130434783e^{(-1.15t)} - 0.4615384615e^{(-1.3t)} + 0.9770664118 + 0.1714285714e^{(-1.4t)}] - tK_2 \quad (23)$$

Setting K_1= 1 and K_2= 0.1, 0.2, 0.3, 0.4, 0.5 in Equation (23), respectively, one can get the Table 6 and correspondingly Figure7.

TABLE 5. Sensitivity of MTTF as a function of failure rates

Variation in λ_1, λ_2, λ_3	$\frac{\partial MTTF}{\partial \lambda_1}$	$\frac{\partial MTTF}{\partial \lambda_2}$	$\frac{\partial MTTF}{\partial \lambda_3}$
0.01	-1527.777777	-160.000000	-5555.555555
0.02	-291.545189	347.222222	-2500.000000
0.03	-62.934027	395.205702	-1360.000000
0.04	10.288065	371.093750	-833.333333
0.05	38.000000	332.510287	-553.935860
0.06	48.418065	293.888889	-390.625000
0.07	51.374716	259.126941	-288.065843
0.08	50.921711	228.949652	-220.000000
0.09	48.905805	203.082767	-172.802404

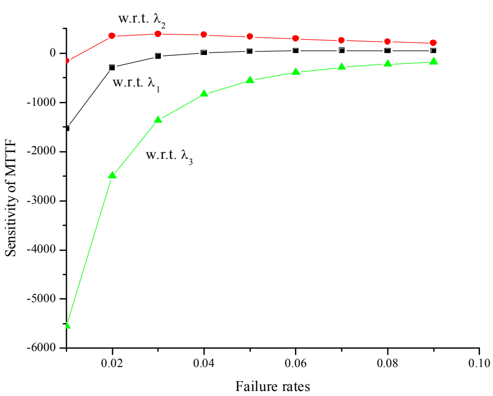

Figure 6. Sensitivity of MTTF as a function of failure rates

TABLE 6. Expected profit as a function of failure rates

Time (t)	Expected profits				
	K_2= 0.1	K_2=0.2	K_2=0.3	K_2=0.4	K_2=0.5
0	0	0	0	0	0
1	0.8999	0.7999	0.6999	0.5999	0.4999
2	1.7995	1.5995	1.3995	1.1995	0.9995
3	2.6988	2.3988	2.0988	1.7988	1.4988
4	3.5979	3.1979	2.7979	2.3979	1.9979
5	4.4968	3.9968	3.4968	2.9968	2.4968
6	5.3957	4.7957	4.1957	3.5957	2.9957
7	6.2945	5.5945	4.8945	4.1945	3.4945
8	7.1931	6.3931	5.5931	4.7931	3.9931
9	8.0917	7.1917	6.2917	5.3917	4.4917
10	8.9901	7.9901	6.9901	5.9901	4.9901

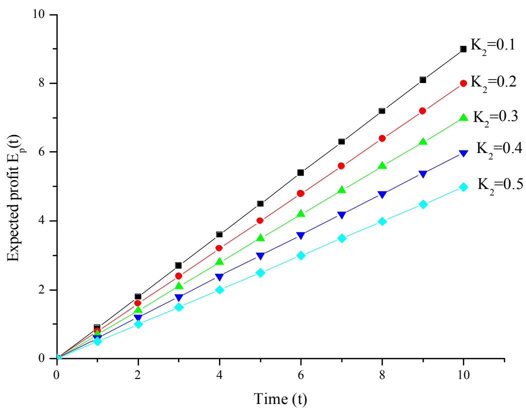

Figure 7. Expected profit as a function of failure rates

7. RESULTS, DISCUSSION AND CONCLUSION

In this paper, we analyzed the availability, reliability, MTTF, sensitivity analysis and cost effectiveness of the coal handling unit of a thermal power plant. For numerically examining the behavior of availability and cost effectiveness, $\lambda_1 = 0.15, \lambda_2 = 0.15, \lambda_3 = 0.10$, $\phi_1 = 1, \phi_2 = 1, \phi_3 = 1$ and for reliability, MTTF and sensitivity analysis of the system, various parameters are fixed as $\lambda_1 = 0.01$, $\lambda_2 = 0.02$, $\lambda_3 = 0.03$, and taking all repairs as zero.

One can easily conclude from Figure 2 that the availability of the system decreases swiftly when the time increases then attain a uniform value. Figure 3 represents the variation of reliability of the system. It shows that the reliability of the system decreases precisely with the increment in time. By critically examining Figure 4, one can conclude that MTTF of the system increases with respect to variation in λ_2, decreases with respect to λ_3 and with respect to λ_1 at first it decreases and then increases. So the MTTF is the highest with respect to λ_3 and the lowest with respect to λ_2.

The sensitivities of the system reliability with respect to λ_1, λ_2 and λ_3 are shown in Figure 5. It reveals that sensitivity initially decreases with time passes. It is clear from the graph that system reliability is more sensitive with respect to λ_3. So, we can conclude that the system can be made less sensitive by controlling its failure rates. Moreover, Figure 6 shows the sensitivity of MTTF with respect to λ_1, λ_2 and λ_3 which shows that it increases with the increment in failure rates. Critical observation of the graph point out that MTTF of the system is more sensitive again with respect to λ_3.

Keeping the revenue cost per unit time fixed as 1 and varying service cost as 0.1, 0.2, 0.3, 0.4, and 0.5 one can obtain Figure 7. It is very clear that the profit decreases as the service cost increases.

From this paper, one can conclude the importance of unit failure which looks like to be possible especially in a coal handling unit of thermal power plant. It is also clear that the sensitivity of the system much more depends upon system failure rates i. e. the system can be made less sensitive by controlling its failures. Using this meticulous reliability model, unit or group of units that affect the system, can be identified accurately. It asserts that the result of this research will be useful to many engineering problems and safety related decisions.

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Reliability Measures Improvement and Sensitivity Analysis of a Coal Handling unit for Thermal Power Plant

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چکیده

مقاله حاضر به بررسی قابلیت اطمینان و آنالیز حساسیت یک واحد حمل و نقل زغال سنگ از یک نیروگاه حرارتی با استفاده از روش احتمال میپردازد. واحد حمل و نقل زغال سنگ بلوک اصلی یک نیروگاه حرارتی است و آن را برای عملکرد خوب یک نیروگاه که منبع تغذیه آن لازم است، که در واحد حمل و نقل زغال سنگ کار ، باید به طور مداوم و بدون هر گونه مانعی باشد . پیکربندی سیستم حمل و نقل زغال سنگ شامل دو زیر سیستم متصل به صورت سری، می باشد همچنین هر زیر سیستم دارای دو واحد به صورت موازی می باشد . سرعت شکست و تعمیر هر دو زیر سیستم ثابت گرفته شده است. با کمک تبدیل لاپلاس و معادلات دیفرانسیل، احتمال تغییر وضعیت، در دسترس بودن، قابلیت اطمینان، MTTF، حساسیت تجزیه و تحلیل و مقرون به صرفه بودن سیستم مورد ارزیابی قرار گرفت.

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