ISSN: 0974-5823 Vol. 7 No. 2 February, 2022

International Journal of Mechanical Engineering

Reliability Evaluation of a Belt Conveyor System using CAS Mathematica

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Abstract - This article evaluates the performance of the belt conveyor system in a coal handling plant through reliability analyses. The belt conveyor system consists of twenty-three belt conveyors subdivided into six segments to ensure good maintenance practices. The performance of the coal handling plant is depended on the reliability of the belt conveyor system. The belt conveyor system is mathematically modelled using the Markovian birth-death concept for analysing the reliability. Various Chapman-Kolmogorov differential equations are formulated for all the system states and solved with the help of CAS Mathematica. The effect of every segment of the belt conveyors on the reliability of the system was analysed using different rates of failures and repairs of respective segments of the belt conveyors has helped the plant to identify the weak-links of the system that need improved maintenance practices to improve the overall performance of the plant.

Index Terms - Markov process, reliability, belt conveyor system, performance evaluation, differential equations

INTRODUCTION

In the current business environment, every industry focuses on the reliability of its systems to sustain the competition. Industry can be competitive only when its production systems are available and reliable for extended operations. Therefore, system reliability analysis has become a vital target for every industry to measure its effectiveness. As industrial systems have grown in complexity and size, investment justifications have demanded higher levels of performance and reliability of the systems (Dhillon B S, 2008). The analysis of reliability helps the management understand the plant's performance and thus provide valuable inputs in decision-making processes (Aven T, 2006). The industry needs to improve system reliability and, as a result, minimise maintenance costs for economically viable operations (Barabady J, 2008). The belt conveyor system is the most complex system among the entire coal handling plant has the maximum economic impact on the plant when it fails. Therefore, reliability evaluation of the belt conveyor system is inevitable in decision-making processes for overall performances improvement of the plant. The analysis of the system's reliability has great importance for the improvement of the system's overall performance and costs of maintenance and operations. The published literature reveals that different methodologies have been proposed for the reliability analysis of several industrial systems. Most of the reliability analyses were used qualitative based analytical methods, but they are lack of accuracies. The popularly used quantitative-based analytical method estimates parameters, but they are not suitable for complex repairable systems with multiple states. The reliability of the belt conveyor system is analysed based on fault data through probability distribution functions. (Li M, 2009). The author investigated the system by fitting the time between failure (TBF) and time to repair (TTR) data in the six standard probability distribution functions to estimate the reliability of the belt conveyors of underground coal mines (Gorai A K, 2017). Another research has proposed an expert judgment method for reliability analysis of a steam boiler due to inadequate life data (Patil, S S, 2020). The ice cream plant is analysed for RAM using probability distribution functions (Tsourohas P, 2020). The reliability of a trend free subsystem is analysed using the classical statistical methods, and power-law processes are used (Gharahasanlou A N). There is little literature on the reliability analysis of various industrial systems using quantitative analysis like stochastic modelling. The mathematical models are most suited for analysis of the complex and repairable systems having multiple states. By applying a probabilistic approach, the reliability of a paper plant has been analysed by taking the exponential distribution for failures and repairs (Khanduja R, 2010), the LNG processing plant (Hassan J, 2016) and the coal handling system (Gupta S, 2009). However, no literature is found on the reliability analysis of a belt conveyor system using a quantitative analytical technique like stochastic analysis models. The belt conveyor system has been analysed for its reliability through a mathematical model developed based on the Markovian approach and solved using the CAS Mathematica. Field data of failures and repairs of the belt conveyor system for three years collected from the plant are used to estimate the rates of failures and repairs of each segment of belt conveyors considered in the analysis model.

SYSTEM CONFIGURATION

The Belt Conveyor System of the Coal Handling Plant comprises 23 separate belt conveyors is subdivided into six Segments as indicated below for effective coal transportation in the plant. The block diagram indicating the flow of coal in the plant is shown in Figure 1.

Segment S1 (Wagon un-loading conveyors) consists of four separate belt conveyors connected in sequence. Failure of any of the conveyors forces the entire system to fail.

Segment S2 (Silo feeding conveyors) consists of three separate belt conveyors connected in sequence. Failure of any of the conveyors forces the entire system to fail. Segment S3 (Crusher feeding conveyors) consists of five separate belt conveyors connected in sequence. Failure of any of the conveyors forces the entire system to fail. Segment S4 (Blending station conveyors) comprise one long conveyor belt and transfers crushed coal from the crusher house to the coal blending station. Failure of this conveyor belt causes the entire system to fail.

Segment S5 (Common-route Conveyor) consists of six separate belt conveyors connected in a sequence. Failure of any of the conveyors forces the entire system to fail. Segment S6 (Coal-tower feeding conveyors) consists of two tracks of conveyors (main and alternate) in parallel of each having two separate belt conveyors in series. When any of the conveyor belt of the main track fails, the belt conveyor system continues to operate by switching over to the alternate track of belt conveyors and vice versa.

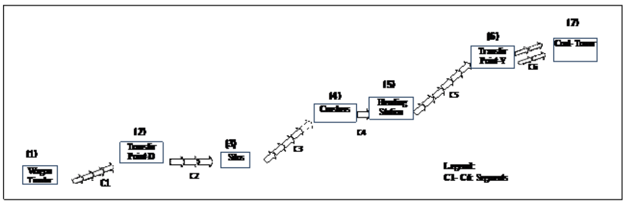

Figure 1.

Block diagram of the flow of coal in coal handling plant

NOMENCLATURES AND ASSUMPTIONS

3.1 Nomenclatures

S1, S2, S3, S4, S5, S6	Working states of respective Segments of the Belt Conveyor System
S_s6	Working state of Segment S6 with stand-by unit
S1, S2, S3, S4, S5 & S6	Failed states of respective Subgroups
Pk (t), k=0,1, 2,..., 11	Probability that the system at time (t), is in k^{th} state
λi, i =1-6	Mean rate of failure of Segments S1 to S6, respectively
μi, i =1-6	Mean repair rate of Segment S1 to S6, respectively
Δ_t	Time increment

3.2 Assumptions

- All Segments of the belt conveyor system are initially operating.
- Repair and failure rates are independent of each other
- The failure/repair characteristics of the systems are associated with exponential distributions.
- In terms of efficiency, a repaired Segment performs just as well as a new Segment
- A standby track of a Segment instantaneously replaces the failed main track of the Segment
- The rate of failures and repairs are statistically distinct and remain stable over time.

MATHEMATICAL MODELLING

All the possible states of the belt conveyor system are shown in the state transition diagram in Figure 2. With the help of the state transition diagram, various Chapman-Kolmogorov differential equations for all states are formulated for the development of a mathematical model of the system with some assumptions. Using the probability considerations on the state transition diagram, a system of differential equations at a time (t+ △t) is generated as follows:

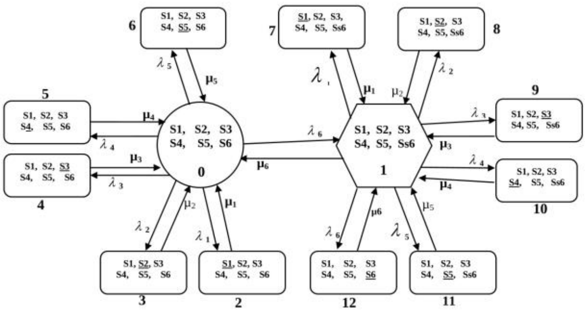

Figure 2.

State transition diagram

eqns =

{P0’ [t] = = - X1* P0 [t] + u1* P2[t] + u2* P3[t] + u3* P4[t] + u4* P5[t] + u5* P6[t] + u6* P1[t]

P1’ [t] = = - X2* P1[t] + u1* P7[t] + u2* P8[t] + u3* P9[t} + u4* P10[t] + u5* P11[t] + u6* P12[t] + L6* P0[t]

P2’ [t] = = L1* P0[t] – u1* P2[t]

P3’ [t] = = L2* P0[t] – u2* P3[t]

P4’ [t] = = L3* P0[t] – u3* P4[t]

P5’ [t] = = L4* P0[t] – u4* P5[t]

P6’ [t] = = L5* P0[t] – u5* P6[t]

P7’ [t] = = L1* P1[t] – u1* P7[t]

P8’ [t] = = L2* P1[t] – u2* P8[t]

P9’ [t] = = L3* P1[t] – u3* P9[t]

P10’[t] = = L4* P1[t] – u4* P10[t]

P11’ [t] = = L5* P1[t] – u5* P11[t]

P12’ [t] = = L6* P1[t] – u6* P12[t]

P0 [0] = = 1

P1 [0] = = 0

P2 [0] = = 0

P3 [0] = = 0

P4 [0] = = 0

P5 [0] = = 0

P6 [0] = = 0

P7 [0] = = 0

P8 [0] = = 0

P9 [0] = = 0

P10 [0] = = 0

P11 [0] = = 0

P12 [0] = = 0**}**

X1 = L1+L2+L3+L4+L5+L6; and X2 = L1+L2+L3+L4+L5+L6+u6

Where, L = Lambda (λ) and u = Miu (μ)

The above system of differential equations is solved using CAS Mathematica. The values of P0, P1, P2………. P12 are estimated at point ‘t’:

```
sol = DSolve [eqns , {P0, P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12}, t]
Plot[{P0[t] /. sol }, {t, 0, 400}, PlotLabel → P0[t]]
{{P0 → Function [{t},
    0.00101205 e^(-1.5306t) (1. e^(1.32757t) + 4.08115 e^(1.32989t) + 6.37496 e^(1.35648t) + 25.7991 e^(1.37726t) +
      1.51119 e^(1.38967t) + 12.7079 e^(1.4043t) - 2.62587 × 10^-29 e^(1.4056t) + 2.33912 e^(1.412t) +
      60.8865 e^(1.42265t) - 4.90672 × 10^-29 e^(1.4306t) + 4.47973 e^(1.44998t) + 868.909 e^(1.5306t))],
  P1 → Function [{t}, -0.00105355 e^(-1.5306t) (1. e^(1.32757t) - 0.0602112 e^(1.32989t) +
      6.466 e^(1.35648t) - 0.365359 e^(1.37726t) + 1.65435 e^(1.38967t) - 0.0766941 e^(1.4043t) -
      1.35372 × 10^-28 e^(1.4056t) + 1.59595 e^(1.412t) - 1.03929 e^(1.42265t) +
      4.25569 × 10^-29 e^(1.4306t) + 4.18023 e^(1.44998t) - 13.355 e^(1.5306t))],

P2 → Function [{t}, -0.0000392924 e^(-1.5306t) (1. e^(1.32757t) + 4.17504 e^(1.32989t) +
      8.86103 e^(1.35648t) + 49.8297 e^(1.37726t) + 3.80428 e^(1.38967t) + 49.7852 e^(1.4043t) +
      9.14834 × 10^-29 e^(1.4056t) + 12.96 e^(1.412t) + 788.623 e^(1.42265t) +
      6.16011 × 10^-13 e^(1.4306t) - 23.8175 e^(1.44998t) - 895.221 e^(1.5306t))],
P3 → Function [{t}, -0.0000129704 e^(-1.5306t) (1. e^(1.32757t) + 4.20605 e^(1.32989t) +
      10.1263 e^(1.35648t) + 71.0265 e^(1.37726t) + 7.40383 e^(1.38967t) + 763.721 e^(1.4043t) +
      9.68876 × 10^-27 e^(1.4056t) - 28.497 e^(1.412t) - 278.715 e^(1.42265t) +
      1.45744 × 10^-27 e^(1.4306t) - 7.87651 e^(1.44998t) - 542.395 e^(1.5306t))],
P4 → Function [{t}, -0.0000515301 e^(-1.5306t) (1. e^(1.32757t) + 4.26762 e^(1.32989t) +
      14.0141 e^(1.35648t) + 409.323 e^(1.37726t) - 8.83157 e^(1.38967t) - 28.4315 e^(1.4043t) -
      9.03561 × 10^-29 e^(1.4056t) - 3.94969 e^(1.412t) - 76.7904 e^(1.42265t) +
      3.34701 × 10^-28 e^(1.4306t) - 3.42401 e^(1.44998t) - 307.178 e^(1.5306t))],

P5 → Function [{t}, -0.000200529 e^(-1.5306t) (1. e^(1.32757t) + 17.3797 e^(1.32989t) -
      0.745989 e^(1.35648t) - 1.6744 e^(1.37726t) - 0.0774645 e^(1.38967t) - 0.522124 e^(1.4043t) -
      3.66694 × 10^-30 e^(1.4056t) - 0.0870123 e^(1.412t) - 2.00307 e^(1.42265t) -
      3.19288 × 10^-29 e^(1.4306t) - 0.113633 e^(1.44998t) - 13.156 e^(1.5306t))],
P6 → Function [{t}, -0.0000491154 e^(-1.5306t) (1. e^(1.32757t) + 4.17504 e^(1.32989t) +
      8.86103 e^(1.35648t) + 49.8297 e^(1.37726t) + 3.80428 e^(1.38967t) + 49.7852 e^(1.4043t) -
      6.31048 × 10^-29 e^(1.4056t) + 12.96 e^(1.412t) + 788.623 e^(1.42265t) -
      4.92809 × 10^-13 e^(1.4306t) - 23.8175 e^(1.44998t) - 895.221 e^(1.5306t))],
P7 → Function [{t}, 0.0000409034 e^(-1.5306t) (1. e^(1.32757t) - 0.0615965 e^(1.32989t) +
      8.98757 e^(1.35648t) - 0.705673 e^(1.37726t) + 4.16467 e^(1.38967t) - 0.300462 e^(1.4043t) -
      3.98135 × 10^-28 e^(1.4056t) + 8.84246 e^(1.412t) - 13.4612 e^(1.42265t) -
      1.9137 × 10^-12 e^(1.4306t) - 22.2251 e^(1.44998t) + 13.7594 e^(1.5306t))],
P8 → Function [{t}, 0.0000135022 e^(-1.5306t) (1. e^(1.32757t) - 0.0620539 e^(1.32989t) +
      10.2709 e^(1.35648t) - 1.00586 e^(1.37726t) + 8.10522 e^(1.38967t) - 4.60918 e^(1.4043t) +
      3.84404 × 10^-12 e^(1.4056t) - 19.4431 e^(1.412t) + 4.75746 e^(1.42265t) +
      2.09799 × 10^-27 e^(1.4306t) - 7.34991 e^(1.44998t) + 8.33651 e^(1.5306t))],
P9 → Function [{t}, 0.0000536429 e^(-1.5306t) (1. e^(1.32757t) - 0.0629623 e^(1.32989t) +
      14.2142 e^(1.35648t) - 5.79671 e^(1.37726t) - 9.66821 e^(1.38967t) + 0.171589 e^(1.4043t) +
      5.68989 × 10^-28 e^(1.4056t) - 2.69481 e^(1.412t) + 1.31076 e^(1.42265t) +
      8.79202 × 10^-29 e^(1.4306t) - 3.1951 e^(1.44998t) + 4.72126 e^(1.5306t))],

P10 → Function [{t}, 0.000208751 e^(-1.5306t) (1. e^(1.32757t) - 0.256411 e^(1.32989t) -
      0.756642 e^(1.35648t) + 0.0237123 e^(1.37726t) - 0.0848029 e^(1.38967t) + 0.00315111 e^(1.4043t) -
      2.62738 × 10^-29 e^(1.4056t) - 0.0593672 e^(1.412t) + 0.034191 e^(1.42265t) -
      2.97096 × 10^-29 e^(1.4306t) - 0.106036 e^(1.44998t) + 0.202205 e^(1.5306t))],
P11 → Function [{t}, 0.0000511293 e^(-1.5306t) (1. e^(1.32757t) - 0.0615965 e^(1.32989t) +
      8.98757 e^(1.35648t) - 0.705673 e^(1.37726t) + 4.16467 e^(1.38967t) - 0.300462 e^(1.4043t) -
      5.26507 × 10^-28 e^(1.4056t) + 8.84246 e^(1.412t) - 13.4612 e^(1.42265t) +
      1.53096 × 10^-12 e^(1.4306t) - 22.2251 e^(1.44998t) + 13.7594 e^(1.5306t))],
P12 → Function [{t}, 0.0000270044 e^(-1.5306t) (1. e^(1.32757t) - 0.0620539 e^(1.32989t) +
      10.2709 e^(1.35648t) - 1.00586 e^(1.37726t) + 8.10522 e^(1.38967t) - 4.60918 e^(1.4043t) -
      1.92202 × 10^-12 e^(1.4056t) - 19.4431 e^(1.412t) + 4.75746 e^(1.42265t) -
      3.81905 × 10^-28 e^(1.4306t) - 7.34991 e^(1.44998t) + 8.33651 e^(1.5306t))]}}
```

The system is considered in the operating state, only when it is in State P0 or State P1. Accordingly, the system's reliability values for various rates of failure and repair of every segment are determined for the time (t) at 0 days to 360 days. Hence the system's reliability is computed as:

R (t) = P0 (t) + P1 (t).

SYSTEM ANALYSIS FOR RELIABILITY

The system's reliability for various combinations of failure rates (λi) and repair rates (μi) of all the Segments of belt conveyors are estimated to investigate their respective impact on the belt conveyor system. However, due to the paucity of space, the reliability values of the main four Segments of the belt conveyor system, i.e., S1, S2, S5 and S6, are only illustrated here.

5.1 The reliability values of the belt conveyor system calculated at different rates of failure (λ_1) and repair ($\mu 1$) of the Segment S1 are shown in Table 1.

Time	Reliability of the system							
	At failure rate of Segment S1 (λ_1)				At repair rate of Segment S1 (μ_1)			
(Days)	**0.004**	**0.005**	**0.006**	**0.007**	**0.1**	**0.2**	**0.3**	**0.4**
30	0.9173028	0.9145005	0.9117154	0.9089473	0.8811703	0.9034539	0.9117154	0.9159089
90	0.9152627	0.9124790	0.9097129	0.9069642	0.8777755	0.9015320	0.9097129	0.9138724
150	0.9152668	0.9124824	0.9097136	0.9069610	0.8777686	0.9015104	0.9097136	0.9138676
210	0.9152572	0.9124741	0.9097131	0.9069653	0.8777714	0.9015086	0.9097131	0.9138590
270	0.9152719	0.9124786	0.9097081	0.9069583	0.8777691	0.9015085	0.9097081	0.9138705
330	0.9152562	0.9124792	0.9097114	0.9069590	0.8777691	0.9015084	0.9097114	0.9138635
360	0.9152607	0.9124768	0.9097099	0.9069594	0.8777691	0.9015084	0.9097099	0.9138688

Table 1

The effect of failure and repair rates of Segment S1 on the reliability of the system

Here λ1 takes values as 0.004, 0.005, 0.006, and 0.007 at μ1=0.3 and λ2=0.001 λ3=0.0027, λ4=0.0006 λ5=0.005, λ6=0.002 and μ2=0.125, μ3=0.15, μ4= 0.2, μ5=0.1, μ6=0.125 are unchanged. The system's reliability reduces from 0.9173028 to 0.9069594 as λ1 rises from 0.004 to 0.007 and reduces by 1.13%. with the time goes up. Similarly, when μ1 takes values as 0.1, 0.2, 0.3, and 0.4 at λ1=0.006 and λ2=0.001, λ3=0.0027, λ4=0.0006, λ5=0.005 λ6=0.002 and μ2=0.125, μ3=0.15, μ4= 0.2, μ5=0.1, μ6=0.125 are unchanged, the system's reliability increases from 0.9069594 to 0.9138688 when μ1 rises from 0.1 to 0.4, and increases by 0.76%. with the time goes up.

5.2 The reliability values of the belt conveyor system computed for different rates of failure (λ_2) and repair ($\mu 2$) of the Segment S2 are shown in Table 2.

Time	Reliability of the system							
	At failure rate of Segment S2 (λ_2)				At repair rate of Segment S2 (μ_2)			
(Days)	**0.001**	**0.0013**	**0.0015**	**0.0018**	**0.125**	**0.15**	**0.175**	**0.2**
30	0.8982740	0.8968884	0.8959670	0.8945885	0.8933308	0.8948443	0.8959670	0.8968253
90	0.8952859	0.8939145	0.8930027	0.8916384	0.8902764	0.8918645	0.8930027	0.8938588
150	0.8952818	0.8939099	0.8929976	0.8916326	0.8902719	0.8918598	0.8929976	0.8938520
210	0.8952841	0.8939124	0.8930002	0.8916354	0.8902742	0.8918623	0.8930002	0.8938615
270	0.8952819	0.8939101	0.8929979	0.8916330	0.8902720	0.8918600	0.8929979	0.8938544
330	0.8952824	0.8939104	0.8929981	0.8916331	0.8902725	0.8918604	0.8929981	0.8938533
360	0.8952824	0.8939105	0.8929982	0.8916332	0.8902724	0.8918604	0.8929982	0.8938533

Table 2

The effect of failure and repair rates of Segment S2 on the reliability of the system

Here λ_2 takes the value as 0.001, 0.0013, 0.0015, and 0.0018 at μ2=0.175. Whereas, λ1=0.004, λ3=0.0027, λ4=0.0006, λ5=0.005, λ6=0.002 and μ1=0.1 μ3=0.15, μ4= 0.2, μ5=0.1, μ6=0.125 are unchanged. The system's reliability reduces from 0.8982740 to 0.8916332 as λ2 increases from 0.001 to 0.0018 and reduces by 0.74 % with the time goes up. Similarly, when μ2 takes values as 0.125, 0.15, 0.175, and 0.2 at λ2=0.0015 and λ1=0.004, λ3=0.0027, λ4=0.0006, λ5=0.005 λ6=0.002 and μ1=0, μ3=0.15, μ4= 0.2, μ5=0.1, μ6=0.125 are unchanged, the system's reliability increases from 0.8916332 to 0.8938533 as μ2 rises from 0.125 to 0.2 and increases by 0.25%. with the time goes up.

5.3 The reliability values of the belt conveyor system computed for different rates of failure (λ_5) and repair ($\mu 5$) of the Segment S5 are shown in Table 3.

Time	Reliability of the system							
	At failure rate of Segment C5 (λ_5)				**At repair rate of Segment C5 (μ_5)**			
(Days)	**0.005**	**0.01**	**0.015**	**0.02**	**0.1**	**0.2**	**0.3**	**0.4**
30	0.9226221	0.9086246	0.8950479	0.8818737	0.8243794	0.8754253	0.8950479	0.9052175
90	0.9208813	0.9069715	0.8934654	0.8803477	0.8201915	0.8739356	0.8934654	0.9035573
150	0.9208858	0.9069588	0.8934569	0.8803449	0.8201752	0.8739338	0.8934569	0.9035488
210	0.9208764	0.9069586	0.8934550	0.8803448	0.8201750	0.8739334	0.8934550	0.9035441
270	0.9208830	0.9069596	0.8934542	0.8803448	0.8201757	0.8739334	0.8934542	0.9035451
330	0.9208812	0.9069597	0.8934539	0.8803447	0.8201750	0.8739333	0.8934539	0.9035452
360	0.9208796	0.9069594	0.8934539	0.8803447	0.8201751	0.8739334	0.8934539	0.9035449

Table 3

The effect of failure and repair rates of Segment S5 on the reliability of the system

Here, λ5 takes value as, 0.005, 0.01, 0.015, and 0.02 at μ5=0.3 and λ1=0.004, λ2=0.001, λ3=0.0027, λ4=0.0006, λ6=0.002 and μ1=0.1 μ2=0.125, μ3= 0.15, μ4=0.2, μ6=0.125 are unchanged. The reliability of the system reduces from 0.9226221 to 0.8803447 as λ5 increases from 0.005 to 0.02 and decreases by 4.6 % with the time goes up. Similarly, when μ5 takes the values as 0.1, 0.2, 0.3, and 0.4 at λ5=0.015 and λ1=0.004, λ2=0.001, λ3=0.0027, λ4=0.0006, λ6=0.002 and μ1=0.1, μ2=0.125, μ3= 0.15, μ4=0.2, μ6=0.125 are unchanged, the reliability of the system increases from 0.8803447 to 0.9035449 as μ5 rises from 0.1 to 0.4 and increases by 2.64 % with the time goes up.

5.4The reliability values of the belt conveyor system computed for different rates of failure (λ_6) and repair ($\mu6$) of the Segment S6 are shown in Table 4.

Time	Reliability of the system							
	At failure rate of Segment C6 (λ_6)				**At repair rate of Segment C6 (μ_6)**			
(Days)	**0.002**	**0.0025**	**0.003**	**0.0035**	**0.125**	**0.156**	**0.187**	**0.218**
30	0.8965992	0.8965494	0.8964888	0.8964175	0.8962827	0.8964100	0.8964888	0.8965412
90	0.8935709	0.8935204	0.8934587	0.8933861	0.8932117	0.8933709	0.8934587	0.8935111
150	0.8935645	0.8935141	0.8934529	0.8933808	0.8932057	0.8933653	0.8934529	0.8935062
210	0.8935647	0.8935144	0.8934530	0.8933806	0.8932081	0.8933652	0.8934530	0.8935059
270	0.8935648	0.8935144	0.8934527	0.8933800	0.8932061	0.8933650	0.8934527	0.8935056
330	0.8935648	0.8935140	0.8934523	0.8933804	0.8932061	0.8933652	0.8934523	0.8935063
360	0.8935646	0.8935141	0.8934525	0.8933803	0.8932062	0.8933652	0.8934525	0.8935058

Table 4

The effect of failure and repair rates of Segment S6 on the reliability of the system

Here, λ6 takes the value as 0.002, 0.0025, 0.003, and 0.0035 at μ6=0.187 and λ1=0.004, λ2=0.001, λ3=0.0027, λ4=0.0006, λ5=0.005 and μ1=0.1 μ2=0.125, μ3= 0.15, μ4=0.2, μ5=0.1 are unchanged. The reliability of the system reduces from 0.8965992 to 0.8933803 as λ6 rises from 0.002 to 0.0035 and decreases by 0.36 % with the time goes up. Similarly, when μ6 takes as 0.125, 0.156, 0.187, and 0.218 at λ6=0.003 and λ1=0.004, λ2=0.001, λ3=0.0027, λ4=0.0006, λ5=0.005 and μ1=0.1, μ2=0.125, μ3= 0.15, μ4=0.2, μ5=0.1 are unchanged, the reliability of the system increases from 0.8933803 to 0.8935058 as μ6 rises from 0.125 to 0.218 and increases by 0.014 % with the time goes up.

RESULTS DISCUSSION

Figure 3, illustrates the impact of the six Segments on the system's reliability based on their respective failure and repair rates for overall analysis of the system.

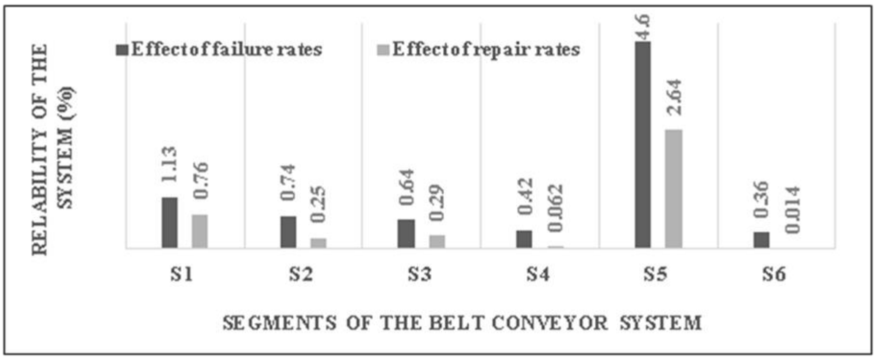

Figure 3

Effect of failure rate and repair rate of Segments on the reliability

From the above comparative analysis, it is understood that Segment S5 (i.e., The common route conveyors) has the maximum impact on the system's reliability i.e., by 4.6% on the effect of its rate of failure (λ5) and by 2.64% on the effect of its rate of repair (μ5). Accordingly, Figures 4 and 5, graphically illustrates the impact of the failure rates (μ5) and repair rates (μ5) of Segment S5 respectively on the system's reliability.

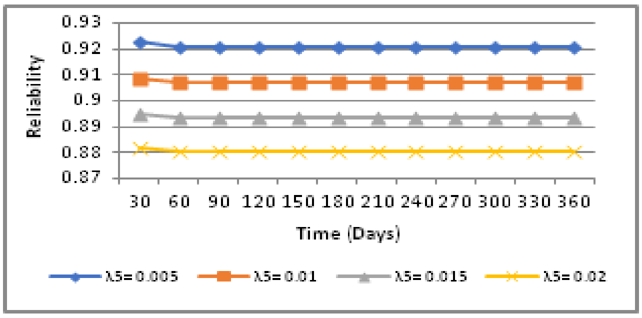

Figure 4

Effect of failure rates of Segment S5 on the system's reliability

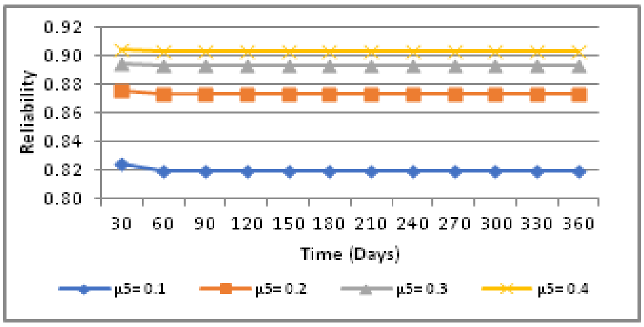

Figure 5

Effect of repair rates of Segment S5 on the system's reliability

From the above analysis, it is found that Segment S5 is the most sensitive Segment of belt conveyors among the entire belt conveyor system as its rates of failures and repairs have the maximum impact on the belt conveyor system.

To improve the reliability of the system, the failure rates and repair rates of the Segment S5 must be improved. Accordingly, the system's existing maintenance procedures and practices must be modified suitably and explicitly, focusing on the weak segments and components and the implementation of improved maintenance strategies.

It is also observed that Segment S5 consists of large number of separate belt conveyors and arranged in series is the major reason for its poor reliability values. Suitable redundancy provision for this crucial Segment S5, could help to improve its system's reliability.

CONCLUSIONS

The stochastic model formulated based on the Markov birth-death process for the system reliability evaluation has effectively identified the weak components of the complex repairable belt conveyor system. The model is very accurate in realistically estimating the reliability values of every Segment of the large-scale belt conveyor system. Hence this model framework helps in evaluating the overall performance status of the coal handling plant. The Segment S5 of the belt conveyor system is identified as the most sensitive and critical Segment of belt conveyors as it has the maximum effect of its failures on the performance of the belt conveyor system. It hence needs more intensified and effective maintenance strategies for its reliability improvement.

This model also helps identify the critical failure and repair rates of every Segment of the belt conveyor system that needs improvement. Even though the application of the Markov approach-based model for reliability evaluation is a complicated and time-consuming process, its findings are accurate and more applied due to its sensitiveness towards changes in the rates of failures and repairs. The results of this study were deliberate with the plant's management, and the findings were considered accurate and valuable for evaluating reliability metrics of the system and hence improving the production performance of the coal handling plant. This analysis document shall also serve as a useful data source for similar performance analyses of other systems.

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