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Reliability Analysis of blowers of a Wastewater Treatment Plant

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Abstract

Blowers of a wastewater treatment plant are analyzed. Real down time data of the two blowers on failures, repairs, and cost incurred in carrying out the maintenance activities, are collected from the plant. Blowers are used to treat the waste and sewage water and convert the same to useful water, which is then used for watering the plants. The high-pressure air is blown through the blowers into the sewage treatment tank, which increases the sewage and air space and removes nitrogen and ammonia from the sewage. The data are summarized using Easy-Fit software for the important descriptive outcomes of the plant. Reliability measures for the system effectiveness are also obtained for both the blowers and compared. Semi- Markov and regenerative processes have been used for analysis.

Keywords: Reliability, Blowers, Wastewater plant, failures, repairs, Semi – Markov, regenerative processes

I. NOMENCLATURE

S_0	Operative state of the blower
S_1	Unit fails due to repairable failure
S_2	Unit fails due to replaceable failure
S_3	Unit fails due serviceable failure
λ_1	Rate of failure of any component of the blower 211
α_1	Repair rate for repairable failures for the blower 211
β_1	Repair rate for replaceable failures for the blower 211

γ_1	Repair rate for serviceable failures for the blower 211
λ_2	Rate of failure of any component of the blower 411
α_2	Repair rate for repairable failures for the blower 411
β_2	Repair rate for replaceable failures for the blower 411
γ_2	Repair rate for serviceable failures for the blower 411
p_1	Probability of occurrence of repairable failures for the blower 211
p_2	Probability of occurrence of replaceable failures for the blower 211
p_3	Probability of occurrence of serviceable failures for the blower 211
q_1	Probability of occurrence of repairable failures for the blower 411
q_2	Probability of occurrence of replaceable failures for the blower 411
q_3	Probability of occurrence of serviceable failures for the blower 411
©	Symbol for Laplace Convolution
Ⓢ	Symbol for Stieltje's convolution
*	Symbol for Laplace Transforms
**	Symbol for Laplace Stieltje's transforms
A_0	Steady state availability of the system
$\emptyset_i(t)$	c.d.f. of first passage time from a regenerative state i to a failed state j
$p_{ij}(t)$, $Q_{ij}(t)$	p.d.f. and c.d.f. of first passage time from a regenerative state I to the regenerative state j or to a failed state j in (0, t].
$g_1(t)$, $G_1(t)$	p.d.f. and c.d.f. of repair rate for repairable failures for the blower 211
$g_2(t)$, $G_2(t)$	p.d.f. and c.d.f. of repair rate for replaceable failures for the blower 211
$g_3(t)$, $G_3(t)$	p.d.f. and c.d.f. of repair rate for serviceable failures for the blower 211
$h_1(t)$, $H_1(t)$	p.d.f. and c.d.f. of repair rate for repairable failures for the blower 411
$h_2(t)$, $H_2(t)$	p.d.f. and c.d.f. of repair rate for replaceable failures for the blower 411
$h_3(t)$, $H_3(t)$	p.d.f. and c.d.f. of repair rate for serviceable failures for the blower 411

*p.d.f.: probability density function

c.d.f.: cumulative distribution function

II. INTRODUCTION

Various industrial systems were analysed in the past under different operating conditions. Various researchers in the past have analysed different industrial systems under different operating conditions and assumptions in understanding the system behaviour in terms of reliability indices and cost benefit analysis. Goel et.al. [1] worked on system analysis with correlated failures and repairs. Systems with assumptions of regular repairmen, tiredness of repairmen, and partial or complete failure units, for analysis was considered by Tuteja et.al. [2]-[5]. Later Rizwan et. al. [6]-[10] extended the previous study and analysed the system for different operating conditions of comparative analysis, rest period of repairman, systems with accident and inspection, hot standby systems. Taneja et. al. [11] worked on a two-unit PLC system with four failures. Rizwan et. al. [12]-[13] dealt with secondary coating line manufacturing machine and a two-unit system with partial failure mode. Rizwan [14]-[17] shown the modeling strategies / applications to an industrial system and system analysis with two repairmen. Zuhair and Rizwan [18] shown an analysis of a two-unit system. Rizwan et. al. [19]-[22] presented studies on programmable logic controllers and continuous casting plant. Mathew et. al. [23]-[31] further studied continuous casting plant with different case studies and variations. Rizwan et. al. [32]-[34] analysed a hot standby system and a desalination plant system and obtained reliability indices of interest. Saud et.al [35]-[36] considered a centrifugal pump of refinery system for analysis. Al-Amri et. al. [37] analysed recycle gas compressor; Al Maqbali et.al. [38] analysed AC compressors; Al-Balushi et.al. [39] analysed a sewage lifting centrifugal pump. Mathew and Rizwan [40] carried out a simple maintenance analysis of port cranes data. Padmavathi et.al. [41]-[46] extensively studied a desalination plant with seven evaporators and obtained various reliability indices along with the cost-benefit analysis of the system. Rizwan et.al. [47]-[49] again considered the desalination plant and variations under different operating conditions of the plant with shutdown during winter season and repair / maintenance on FCFS basis, and inspections were studied. Sharma and Kaur [50]-[51] studied the standby systems with three failure categories and the compressor systems with and without provision of priority to failed compressor unit. Rizwan et.al. [52]-[56] estimated the relevant reliability indices of the different case specific situations of the wastewater treatment plant and anaerobic batch reactor treating fruits and vegetables waste. Rizwan & Mathew [56] carried out the port cranes analysis under minor and major categories of electrical and mechanical components failures of cranes. Later, Al-Rahbi et.al. [57]-[65] focused on the rodding anode plant in aluminium industry where different plant situations are explored for subsystems and main system under multiple repairmen and multiple unit’s maintenance management strategies. Much has been discussed by Taj et.al. [66]-[76] about a cable plant sub-systems and the main system as single machine, different failure types, with storage of surplus produce, winter operating strategy, comparative study between the models, and a review mentioning about the future scope of using new distributions and fuzzy optimization models. Recently, Rizwan and Taj [77] analysed a PLCs controlled port system and obtained the reliability indices of interest reflecting the system effectiveness.

The main focus of the entire literature is to analyse the complex industrial systems from reliability perspective and obtain the relevant indices reflecting the system behaviour. One such plant in Oman has been identified and analysed as a potential case study to understand the operational capabilities of the plant by obtaining reliability indicators. For the purpose of analysis, 8 years of maintenance data of the two blowers have been collected from the plant. Failure and repair rates obtained therein have been estimated from the data for further analysis.

In wastewater treatment, the blowers ensure the supply of oxygen needed when high-pressure air is blown into the sewage treatment tank, which increases the sewage and air space and removes nitrogen and ammonia from the sewage. Moreover, complex microbes in activated sludge and organic nutrients in wastewater forms a complex food chain. The first to carry out the disinfection task are the oxygen-producing bacteria and spongy fungi. Bacteria, especially spherical bacteria, play the most important role. The role of air blower is to provide oxygen to the bacteria. The air blower works by pumping air to them. The air contains oxygen, so that they can survive and provide better conditions for survival.

In the wastewater treatment plant identified, two types of blowers AR: BLW-411 and AR: BLW-211 are used to treat the waste and sewage water and convert the same to useful water which can be used for plants. AR: BLW-411 is a Positive Displacement Blower, and it supplies the air to Pre-Aeration tanks 1 and 2 to remove ammonia from the sewage water to the great Chambers 1 and 2. Moreover, this blower supplies air to Sludge storage1and 2 to allow the bacteria to grow and to separate the sludge from the sewage water. AR: BLW-211 is a Centrifugal Blower used at Biological Treatment Area where the air is pumped into the sludge seeds to allow bacteria to grow through the sludge seeds and later the bacteria will be removed by pumping air. Also, it's used to supply air to Aeration tanks and membranes.

Mainly, two types of maintenance, Corrective and Preventive maintenance are carried out on the blowers. Corrective maintenance is performed whenever there is a leakage or a repair with the components of the blowers. It is a series of operations that are performed to repair and to calibrate the blowers according to a set time plan. Preventive maintenance operations are carried out daily, weekly, monthly and yearly which includes the periodic inspection of the different components of the blowers, cleaning, lubricating, oiling and changing some of the minor components if necessary to extend the useful lifetime of the blowers.

Both the blowers are analyzed probabilistically using semi-Markov processes and regenerative point techniques. The mean times to system failure and the unit availability are estimated numerically for both the blowers and compared.

III. SUMMARISATION OF THE DATA

Estimated Rates for Blower 211:

Estimated rate of failure of any component of the blower 211(λ_1) = 0.0000138 per hour

Estimated repair rate for repairable failures for the blower 211(α_1) = 0.007546 per hour

Estimated repair rate for replaceable failures for the blower 211(β_1) = 0.002364 per hour

Estimated repair rate for serviceable failures for the blower 211(γ_1) = 0.00497 per hour

Probability of occurrence of repairable failures for the blower 211 (p_1) = 0.13636

Probability of occurrence of replaceable failures for the blower 211 (p_2) = 0.12121

Probability of occurrence of serviceable failures for the blower 211 (p_3) = 0.74242

Estimated Rates for Blower 411:

Estimated rate of failure of any component of the blower 411 (λ_2)= 0.0000169 per hour

Estimated repair rate for repairable failures for the blower 411(α_2) = 0.02551 per hour

Estimated repair rate for replaceable failures for the blower 411(β_2) = 0.05303 per hour

Estimated repair rate for serviceable failures for the blower 411(γ_2) = 0.00503 per hour

Probability of occurrence of repairable failures for the blower 411 (q_1) = 0.15152

Probability of occurrence of replaceable failures for the blower 411 (q_2) = 0.21212

Probability of occurrence of serviceable failures for the blower 411 (q_3) = 0.63636

IV. STATE TRANSITION TABLE

The description of the states for both the blowers is depicted by the state transition table (Table 1):

Table 1: State Transition Table

S_i	S_0	S_1	S_2	S_3
S_0	0	$P\lambda$	$Q\lambda$	$R\lambda$
S_1	α	0	0	0
S_2	β	0	0	0
S_3	γ	0	0	0

$For\ Blower\ 211, \lambda = \lambda_1, \alpha = \alpha_1, \beta = \beta_1, \gamma = \gamma_1, P = p_1, Q = p_2, R = p_3$

$For\ Blower\ 411, \lambda = \lambda_2, \alpha = \alpha_2, \beta = \beta_2, \gamma = \gamma_2, P = q_1, Q = q_2, R = q_3$

V. TRANSITION PROBABILITIES AND MEAN SOJOURN TIMES

A state transition table showing the possible states of transition of the blowers is shown in Table 1. The epochs of entry into states 2, 3, and 4 are regeneration points. The transition probabilities are given by,

$$dQ_{01} = p_1 e^{-\lambda t} dt,\ dQ_{02} = p_2 e^{-\lambda t} dt,$$
$$dQ_{03} = p_3 e^{-\lambda t} dt,\ dQ_{10} = \alpha e^{-\alpha t} dt,$$
$$dQ_{20} = \beta e^{-\beta t} dt,\ dQ_{30} = \gamma e^{-\gamma t} dt \qquad (1\text{-}6)$$
$$For\ Blower\ 211, \lambda = \lambda_1, \alpha = \alpha_1, \beta = \beta_1, \gamma = \gamma_1$$
$$For\ Blower\ 411, \lambda = \lambda_2, \alpha = \alpha_2, \beta = \beta_2, \gamma = \gamma_2$$

The transition probabilities p_{ij} are given below:

$$p_{01} + p_{02} + p_{03} = 1$$
$$p_{10} = p_{20} = p_{30} = 1 \qquad (7\text{-}10)$$

The mean sojourn time, μ_i in the regenerative state '*i*' is defined as the time of stay in that state before transition to any other state. If *T* denotes the sojourn time in the regenerative state '*i*', then:

$$\mu_i = E(T) = P(T > t);\ \mu_0 = \int_0^\infty e^{-\lambda t}\, dt = \frac{1}{\lambda} \qquad (8)$$

The unconditional mean time taken by the system to transit, for any regenerative state 'j' when it (time) is counted from the epoch of entry into state 'i' is mathematically stated as:

$$m_{ij} = \int_0^\infty t\, dQ_{ij}(t) = -q_{ij}^{*\prime}(0),\ \sum_j m_{ij} = \mu_i$$

VI. THE MATHEMATICAL ANALYSIS

A. Mean time to system failure

Regarding the failed states as absorbing states and applying the arguments used for regenerative processes, the following recursive relation for $\phi_i(t)$ is obtained:

$$\varnothing_0(t)=Q_{01}(t)+Q_{02}(t)+Q_{03}(t) \quad (9)$$

Now the mean time to system failure (MTSF) when the unit started at the beginning of state 0, is

$$MTSF = \lim_{s\to 0} \frac{1-\varnothing_0^{**}(s)}{s} = \frac{1}{\lambda} \quad (10)$$

$For\ Blower\ 211, \lambda = \lambda_1$

$For\ Blower\ 411, \lambda = \lambda_2$

B. Availability Analysis of the Unit of the Plant

Using the probabilistic arguments and defining $A_i(t)$ as the probability of unit entering into upstate at the instant t, given that the unit entered in regenerative state i at t=0, the following recursive relations are obtained for $A_i(t)$:

$A_0(t)=M_0(t)+q_{01}(t)©A_1(t)+q_{02}(t)©A_2(t)+q_{03}(t)©A_3(t)$,

$A_1(t) = q_{10}(t) ©A_0(t)$,

$A_2(t) = q_{20}(t) © A_0(t)$

$A_3(t) = q_{30}(t) ©A_0(t)$

Where $M_0(t) = e^{-\lambda t}$, (11-14)

Taking Laplace Transforms of the above equations and solving them for $A_0^*(s)$, using the determinants method the following is obtained:

$$N_1(s) = \begin{vmatrix} M_0^*(s) & -q_{01}^*(s) & -q_{02}^*(s) & -q_{03}^*(s) \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

$$D_1(s) = \begin{vmatrix} 1 & -q_{01}^*(s) & -q_{02}^*(s) & -q_{03}^*(s) \\ -q_{10}^*(s) & 1 & 0 & 0 \\ -q_{20}^*(s) & 0 & 1 & 0 \\ -q_{30}^*(s) & 0 & 0 & 1 \end{vmatrix}$$

$$A_0 = \lim_{s\to 0} sA_0^*(s) = \frac{N_1(0)}{D_1'(0)} = \frac{\frac{1}{\lambda}}{\frac{1}{\lambda}+\frac{1}{\alpha}+\frac{1}{\beta}+\frac{1}{\gamma}} \quad (15)$$

$For\ Blower\ 211, \lambda = \lambda_1, \alpha = \alpha_1, \beta = \beta_1, \gamma = \gamma_1$

$For\ Blower\ 411, \lambda = \lambda_2, \alpha = \alpha_2, \beta = \beta_2, \gamma = \gamma_2$

Using the data as summarized in Section III and various expressions for reliability indicators obtained therein is sections IV & V, the following values of unit effectiveness are estimated:

Mean Time to Failure for the blower 211=72,267 hours

Availability (A_0) for the blower 211 = 0.9896

Mean Time to Failure for the blower 411 = 59098 hours

Availability (A_0) for the blower 411 = 0.9957

VI. DESCRIPTIVE STATISTICS USING EASY- FIT SOFTWARE FOR THE BLOWERS 211 & 411

Table 2: Descriptive Statistics for failure times of Blower 211

Descriptive Statistics

Statistic	Value	Percentile	Value
Sample Size	66	Min	17520
Range	86760	5%	26526.0
Mean	72267.0	10%	36480
Variance	5.6995E+8	25% (Q1)	54720
Std. Deviation	23874.0	50% (Median)	76200
Coef. of Var.	0.33035	75% (Q3)	93360
Std. Error	2938.6	90%	99168.0
Skewness	-0.57228	95%	1.0259E+5
Kurtosis	-0.76713	Max	1.0428E+5

Table 3: Descriptive Statistics for failure times of Blower 411

Descriptive Statistics

Statistic	Value	Percentile	Value
Sample Size	33	Min	26280
Range	74400	5%	26280
Mean	59098.0	10%	27144.0
Variance	6.1425E+8	25% (Q1)	33120
Std. Deviation	24784.0	50% (Median)	62040
Coef. of Var.	0.41937	75% (Q3)	78060
Std. Error	4314.3	90%	96168.0
Skewness	0.13717	95%	98664.0
Kurtosis	-1.3119	Max	1.0068E+5

VII. CONCLUSION

Easy- fit outcomes as obtained in Tables 2 & 3 reveals that the average time to failure for the Blower 211 is 72,267 hours and for the blower 411 is 59098 hours. The expected time for which the Blower 211 is in operation before it completely fails is more than the blower 411 which is also shown in Section VI. Further to this, the coefficient of variation for failure time is less for blower 211 compared to blower 411. The analytical results obtained in section VI B shows that the availability index for blower 411 is slightly better than the blower 211.

Therefore, good maintenance practices and scheduled inspections need to be reviewed in order to improve the operational capabilities of the blower 411 when compared to Blower 211.

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