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Analysis of a System with Effect of Temperature on Operation in High Temperature Zones

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Abstract

This paper addresses the effect of temperature on operation in high temperature zones. As the information has been gathered from a fabric manufacturing company, therefore, it is necessary to give explanation of how system work and its components to make them readily understandable. In that particular industry if room temperature is beyond 22^0c, the system gets stopped due to dipping down because the fabric quality is destroyed in these circumstances. This happens only in summer for the organization considered for the model. The applicability of the model is analyzed by means of a real dataset using three methods goodness-of-fit criteria, goodness-of-fit statistics and classical goodness-of-fit plots**.** Various measures of system effectiveness are obtained by using Markov process and regenerating point technique. Using these measures MTSF, availability, profit of the system is evaluated. The conclusions concerning the reliability and profit of the system are drawn on the basis of graphical study.

Keywords: Fabric Manufacturing Company, Regenerating Point Technique, Temperature, MTSF, Availability, Profit Analysis.

1. INTRODUCTION

Lot of varieties of systems can be seen in the industrial world to meet different types of need/demand of the people. Great challenge for researchers is to produce high quality products at minimum cost. Thus, reliability and profit analysis plays a explanation task in defining quality of system. Literature of reliability contains good contribution on models for industrial systems. Singh and Pandey (1988), Welke et al. (1995), Jiang et al. (2012), Zhag et al. (2012), El-Damcese and Shama (2014), Sachdeva and Taneja (2016) and Busra et al. (2017) have been carried out the profitable aspects for the systems which worked under different situations. But none of them is considering the temperature-dependent operation. Considering this gap in mind reliability models are developed for systems whose working is affected by temperature. Keeping this in view, Sheetal et al. (2018) analyzed reliability and profit of a system with effect of temperature on operation. In this present paper, we investigate a fabric manufacturing company, then find out the reliability and cost-benefit analysis of a temperature dependent system. As change in temperature affects the production of system also, hence sometimes, the system needs to be shut down when the temperature is rise beyond the limit considered for the location. The system in the down is made operative as soon as possible by using air conditioners and other means. The probabilistic analyses of the system is analyzed by making use of regenerative point technique and have obtained various measures of system effectiveness such as Mean time to system failure, Availability in summer, Availability in winter, Busy period of the repairman and expected number of the visits of the repairman. The profit aspect has also been taken into consideration to arrive at a conclusion regarding the information gathered from the fabric manufacturing company.

Other Assumptions for the Model are:

1. Initially, the system is considered as working within acceptable limit of temperature.
2. All the random variables follow arbitrary distributions.
3. After each repair, the system becomes like a new one.

2. Notations

$h_1(t), H_1(t)$	p.d.f. and c.d.f. of time during which the temperature increases beyond specified limit
$f(t), F(t)$	p.d.f. and c.d.f. of failure time
$g(t), G(t)$	p.d.f. and c.d.f. of repair time
$h_2(t), H_2(t)$	p.d.f and c.d.f. of time during which the temperature is controlled to acceptable range
$D_{01}(t)$	$h_1(t)\bar{F}(t)$
$D_{02}(t)$	$f(t)\overline{H_1}(t)$
$D_0(t)$	$\overline{H_1}(t)\bar{F}(t)$

3. ANALYSIS OF MODEL-1

3.1 Transition Probabilities and Mean Sojourn Time

The transition diagram showing various states of transition of system are shown in **Fig. 3.1.** The epochs of entry into the states 0, 1 and 2 are regenerative states. State 1 is the down states The possible transition probabilities are given by:

$$q_{01}(t) = h_1(t)\bar{F}(t) = D_{01}(t) \quad q_{10}(t) = h_2(t)$$

$$q_{02}(t) = f(t)\overline{H_1}(t) = D_{02}(t) \quad q_{20}(t) = g(t)$$

The non–zero elements $p_{ij} = \lim_{s\to 0} q_{ij}*(s)$, are therefore, given as follows:

$$p_{01} = D^*_{01}(0),\ p_{02} = D^*_{02}(0),\ p_{10} = h^*_{10}(0),\ q_{20} = g^*_{20}(0)$$

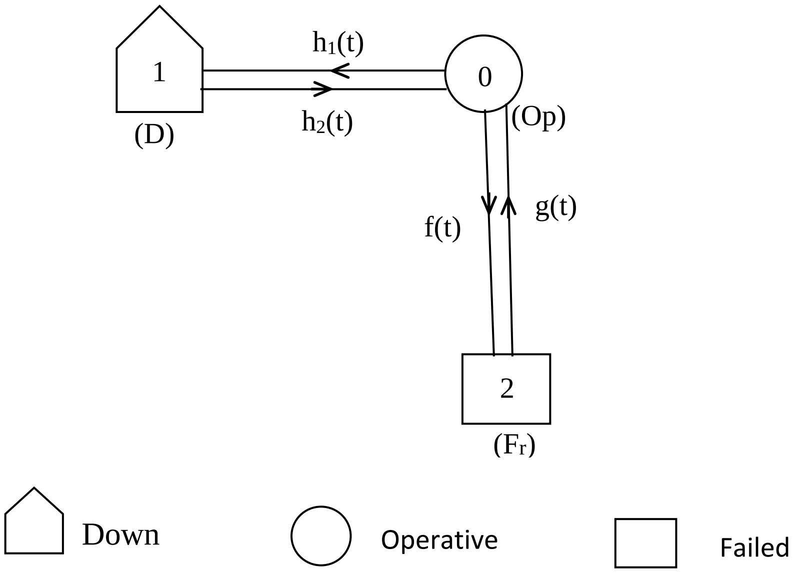

Fig.1 State Transition Diagram

We may be verified that

$$p_{01} + p_{02} = 1 \ , \ p_{10} = p_{20} = 1$$

Mean sojourn times (μ_i) are:

$$\mu_0 = \int_0^\infty \overline{H_1}(t)\bar{F}(t)dt = \int_0^\infty D_0(t)dt$$

$$\mu_2 = \int_0^\infty \bar{g}(t)dt = -g*'(0)$$

$$\mu_1 = \int_0^\infty \overline{H_2}(t) = \int_0^\infty t\,h_2(t)dt = -h_2*'(0)$$

Sum of the **unconditional mean times** (m_{ij}) taking transitions from state i formed out as:

$$m_{01} + m_{02} = \int_0^\infty t(h_1(t)\bar{F}(t) + f(t)\overline{H_1}(t))\,dt = K_0(\text{say})$$

$$m_{10} = \int_0^\infty t(h_2(t))dt = \mu_1$$

$$m_{20} = \int_0^\infty t(g(t))\,dt = \mu_2$$

3.2 Reliability and Mean Time to System Failure (MTSF)

Recursive relations for $\phi_i(t)$ are:

$$\phi_0(t) = Q_{01}(t) \circledS \phi_1(t) \ + Q_{02}(t)$$

$$\phi_1(t) = Q_{10}(t) \circledS \phi_0(t)$$

Taking Laplace Stieltjes Transforms (L.S.T.) of the above relations and solving them for $\phi_0**(s)$, the mean–time to system failure (MTSF) when the system starts from the state ‘0’ is

$$\text{MTSF} = \lim_{s\to 0}\frac{1-\phi_0**(s)}{s} = \lim_{s\to 0}\frac{D(s)-N(s)}{sD(s)} = \frac{N}{D}$$

where

$$N(s) = Q_{02}**(s), \ D(s) = 1 - Q_{01}**(s)Q_{10}**(s)$$

$N = p_{02}$ and $D = 1-p_{01}$

3.3 Availability Analysis

By probabilistic arguments, we obtain the following recursive relations for $A_i(t)$

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

$A_1(t) = q_{10}(t)$ © $A_1(t)$

$A_2(t) = q_{20}(t)$ © $A_0(t)$

where $M_0(t) = \overline{H_1}(t)\bar{F}(t)$

Taking Laplace Transforms (L.T.) of these above relations and solving them for $A_0*(s)$, the steady-state, the availability of the system is given by

$$A_0 = \lim_{s\to 0}(sA_0*(s)) = \lim_{s\to 0}\left(s\frac{N_1(s)}{D_1(s)}\right) = \frac{N_1}{D_1}$$

where

$N_1(s) = M_0*(s)$, $D_1(s) =$

$1 - q_{10}^*(s)q_{10}^*(s) - q_{02}^*(s)q_{20}^*(s)$, $N_1 = M_0$ and

$D_1 = \mu_0 + p_{01}\,\mu_1 + p_{02}\,\mu_2$

3.4 Busy Period Analysis

By probabilistic arguments, we obtain the following recursive relations for $B_i(t)$:

$B_0(t) = q_{01}(t) © B_1(t) + q_{02}(t) © B_2(t)$

$B_1(t) = q_{10}(t) © B_0(t)$

$B_2(t) = q_{20}(t) © B_0(t) + W_2(t)$

where

$$W_2(t) = \overline{G}(t)$$

Taking Laplace Transform of the above $B_i(t)$ relations and solving them for $B_0^*(s)$, the steady–state the total fraction of time for which the system is under repair is given by

$$B_0 = \lim_{s\to 0}(sB_0^{**}(s)) = \lim_{s\to 0}(s\frac{N_2(s)}{D_1(s)}) = \frac{N_2}{D_1}$$

where

$N_2(s) = W_2^*(s)\, q_{02}^*(s)$ and $N_2 = W_2 p_{02}$

3.5 Expected Down Time

The recursive relations for $DT_i(t)$ are:

$$DT_0(t) = q_{01}(t) © DT_1(t) + q_{02}(t) © DT_2(t)$$

$$DT_1(t) = q_{10}(t) © DT_0(t) + W_1(t)$$

$$DT_2(t) = q_{20}(t) © DT_0(t)$$

where

$$W_1(t) = \overline{H}_2(t)$$

Taking Laplace Transform of the above $DT_i(t)$ relations and solving them for $DT_0^*(s)$, the steady–state the total fraction of time for which the system is under down time is given by

$$DT_0 = \lim_{s\to 0}(sDT_0^{**}(s)) = \lim_{s\to 0}(s\frac{N_3(s)}{D_1(s)}) = \frac{N_3}{D_1}$$

where

$N_3(s) = W_1^*(s)\, q_{01}^*(s)$ and $N_3 = W_1\, p_{01}$

3.6 Expected Number of Visits by the Repairman

By probabilistic arguments, we obtain the following recursive relations for $V_i(t)$:

$V_0(t) = Q_{01}(t) Ⓢ V_1(t) + Q_{02}(t) Ⓢ [1+ V_2(t)]$

$V_1(t) = Q_{10}(t) Ⓢ V_0(t)$

$V_2(t) = Q_{20}(t) Ⓢ V_0(t)$

Taking Laplace-Stieltjes Transform (L.S.T) of the above relations and solving them for $V_0^{**}(s)$, the expected number of visits per unit time by the repairman is given by

$$V_0 = \lim_{s\to 0}(sV_0^{**}(s)) = \lim_{s\to 0}(s\frac{N_4(s)}{D_1(s)}) = \frac{N_4}{D_1}$$

where $N_4(s) = Q_{02}^{**}(s)$ and $N_4 = p_{02}$

3.7 Expected number of times the temperature is controlled whenever it reaches beyond the acceptable limit

By probability arguments, we obtain the following recursive relations for $TM_i(t)$:

$TM_0(t) = Q_{01}(t)$ Ⓢ $[1+TM_1(t)] + Q_{02}(t)$ Ⓢ $TM_2(t)$

$TM_1(t) = Q_{10}(t)$ Ⓢ $TM_0(t)$

$TM_2(t) = Q_{20}(t)$ Ⓢ $TM_0(t)$

Taking Laplace-Stieltjes Transform (L.S.T) of the above relations and solving them for $TM_0^{**}(s)$, the expected number of times the temperature is controlled whenever it reaches beyond the acceptable limit is given by

$$TM_0 = \lim_{s\to 0}(sTM_0^{**}(s)) = \lim_{s\to 0}(s\frac{N_5(s)}{D_1(s)}) = \frac{N_5}{D_1}$$

where

$N_5(s) = Q_{01}^{**}(s)$ and $N_5 = p_{01}$

3.8 Profit Analysis

The expected profit incurred to the system is the excess of revenue over cost and in steady state is given by

Profit (P_0) = $C_0A_0 - C_1B_0 - C_2(DT_0) - C_3V_0 - C_4(TM_0)$

where

- C_0: Revenue per unit up time
- C_1: cost per unit time for which the repairman is busy for repair
- C_2: Good will loss per unit time during which the system remains in down
- C_3: cost per visit of the repair man
- C_4: cost per unit time during which the temperature is controlled within acceptable range

3.9 Numerical Results and Graphical Analysis

The following particular case is considered for numerical calculations where all the random variables have been assumed to follow exponential distribution.

$f(t) = \lambda e^{-\lambda t}$ $h_1(t) = \alpha_1 e^{-\alpha_1 t}$

$h_2(t) = \alpha_2 e^{-\alpha_2 t}$ $g(t) = \alpha e^{-\alpha t}$

and hence

$$p_{01} = \frac{\alpha_1}{(\lambda + \alpha_1)}, \quad p_{02} = \frac{\lambda}{(\lambda + \alpha_1)}, \quad p_{10} = p_{20} = 1,$$

$$\mu_0 = K_0 = \frac{1}{(\lambda + \alpha_1)}, \ \mu_1 = \frac{1}{\alpha_2}, \ \mu_2 = \frac{1}{\alpha}$$

Using the values estimated from the data collected as obtained in Chapter 2 i.e. λ=0.04167, α=1, α_1= 0.0455, α_2=0.75, the values of various measures of system effectiveness are obtained as:

- Mean Time to System Failure (MTSF) = 25.46966 hour
- Steady-state Availability (A_0) =0.919729
- Expected Busy Period (B_0) =0. 092996
- Expected Fraction of Down Time (DT_0) =0.10751
- Expected Number of Visits of the Repairman (V_0) = 0. 038325
- Expected Number of Times the Temperature is Maintained whenever it Reaches Beyond the Acceptable Limit (TM_0)=0.042308
- Profit incurred per hour to the system(P)=2756.454

Nature of MTSF and Availability with regard to various rates have been depicted as shown in **Fig. 2** and **3** which reveal that MTSF/Availability decreases as failure rates increases. However, they have higher values for higher values of repair rate(α) and rate which the temperature rises beyond the specified limit (α_1).

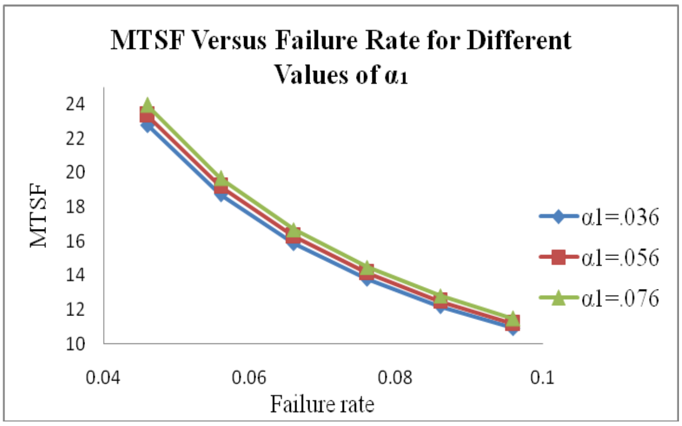

Fig.2

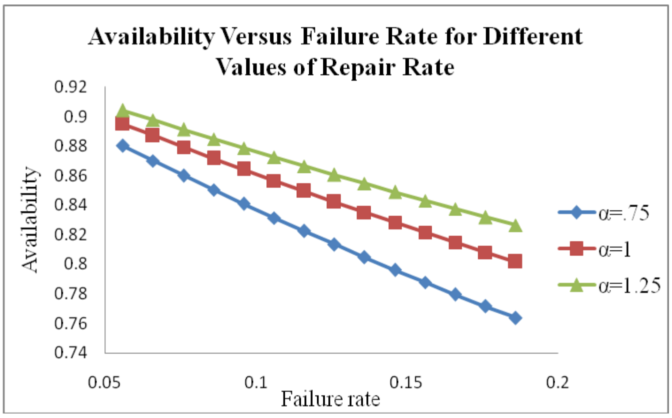

Fig. 3

Profit versus revenue per unit up time (C_0) for different values of goodwill loss per unit time during which the system remains in down (C_1) is shown in **Fig. 4** It is concluded from the graph that:

- Profit increases with increase in the value of C_0 and whereas its values get lowered with increase in the value of C_1.
- Cut-off points for C_0 have been obtained as shown in **Table-1**; in order to fix the price of the product in such a way that no one should get negative profit.

Profit versus cost for maintaining the temperature (C_4) for different values of rate with which the temperature rises beyond specified limits (α_1) is shown in **Fig. 5.** It is concluded from the graph that:

- Profit decreases with increase in the values of C_4 and as well as that of α_1.
- Cut-off points for C_4 have been obtained to know the values as to when the system gives positive or negative profit.

Values of parameters taken and cut-off points obtained in Fig. 4 and 5 are tabulated as follows:

Table. 3.1

Fixed Parameter	Profit		Profit ≥ 0 if	
	Increases	Decreases		
C_2=1000, C_2=1000, C_3=1000, C_4=1000, λ= 0.04167, α=0.75	with increase in C_0	with increase in C_1	C_1=2000	$C_0 \geq$1391.901
			C_1=2200	$C_0 \geq$2091.3031
			C_1=2400	$C_0 \geq$2201.9401
C_0=5000, C_2=1000, C_3=1000, λ= 0.04167, α=0.75	with dicrease in α_1	with increase in C_4	α_1=0.66	$C_4 \leq$2836.1154
			α_1=0.76	$C_4 \leq$2078.2921
			α_1=0.86	$C_4 \leq$1521.2301

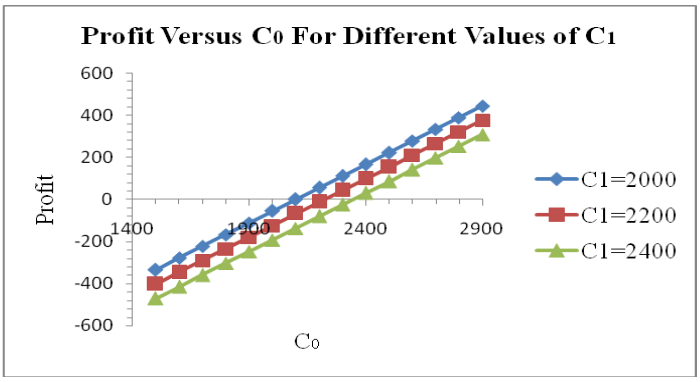

Fig. 4

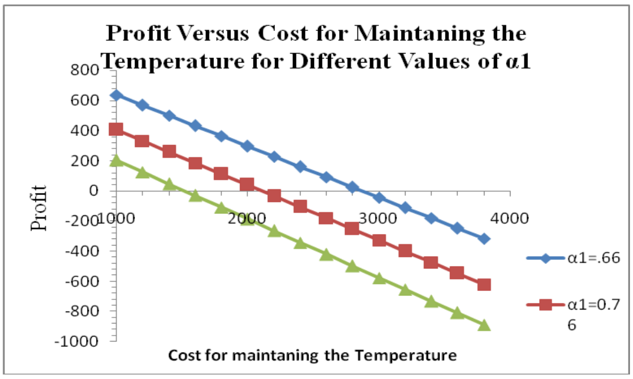

Fig. 5

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