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Profit Analysis of the Boiler Unit in Coal-Fired Power Plant Using RPGT

Sandeep Kundu
Assistant Professor of Mathematics, Govt. College Kheri Chopta (Hisar)
Sandeepkundu1984@gmail.com

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Abstract: In the present paper, we describethe boiler unit of a coal-fired thermal power plant. The boiler unit consists of five subsystems arranged in series and parallel based configurations. A single repairman who examines and repairs the units as and when need emerge. Availability of boiler unit in coal-fired plant is determined with the assistance of RPGT and accessibility of the arrangement of boiler unit for various values of repair and failure rates of subsystems is additionally determined. Profit optimization is discussed with the help of graph and table.

Keywords: Transition diagram, Availability, RPGT

1. Introduction

Manufacturing processes entail a continuous flow of raw materials through a set of sequential procedures that transform them into finished goods. During the production process, industries producing products such as paper, power plants, engineering plants, chemicals, and sugar, among others, have such continuous operations. In many businesses, the goal of high productivity with minimal standby units, storage capacity, production losses, and failure costs is challenging to attain. As a result, the need of high system dependability and availability has been recognized, which can be attained by quantitative management methods based on various Industrial Engineering and Operation Research principles.The quantitative examination of system availability and reliability provides factual information in the form of failure and repair parameters for distinct subsystems. Various systems are prone to random failures as a result of bad design, a lack of operating skills, and incorrect manufacturing procedures, among other factors, resulting in significant production losses. Through good maintenance planning and control, failing systems can be brought back to working order with minimal downtime. Factory operating conditions and repair strategic plans are critical in keeping the system fault-free for as long as possible.This can only be done by conducting a quantitative analysis of each operational component of the plant in question. If the real system is mathematically modeled and studied in actual operating settings, the system performance can be defined in terms of availability. Several academics in the field of dependability theory have been drawn to mechanical systems.The major goal of this article, according to Kumar et al. (2019), is to examine a washing unit in the paper industry using RPGT. Kumar et al. (2018, 2017) investigated the behavior of a bread system and a plant that refines edible oils. Kumar et al. (2019) used RPGT to investigate a cold standby framework with priority for preventative maintenance that has two identical subunits with server failure. Goyal and Goel (2015) used the RPGT technique to study behavior with perfect and imperfect system switch-over. Kumari et al. (2021) used PSO to investigate constrained problems.When failure and repair rates are both variable but stable, the present article additionally considers time-dependent as well as consistent state accessibility. For numerous decisions among component failure/repair rates, the created mathematical issue has been treated methodically but also numerically. The fuzzy concept is utilized to identify the failure criteria for a unit. Assuming the worker's report is correct, that unit is not recoverable and must be replaced. The system transition diagram was created using exceptional failure rates, typical repair rates, and varying probabilities to determine major, secondary, and then tertiary circuits, as well as the base state.Formulations for system characteristics such as MTSF, reliability, number of server visits, and server of busy time have been analyzed to analyses the behavior of the framework under steady state. Specific cases are developed to investigate the effect of failure/repair frequencies on MTSF, availability, and estimated number of visitors, particularly during peak periods. Profitability improvement has also been discussed. The behavior of the system is represented using graphs and tables.

2. System Description

The Boiler system consists of four sub-systems.

Furnace, indicated by A failure/disappointment of which results into disappointment of system.

Boiler-drum, Indicated by B, having single unit, disappointment of which consequences into framework failure.

Economizer, indicated by C, disappointment of which consequences into framework failure

Heater, denoted by D, having two sub units, i.e. one is super-heater and second is re-heater.

2.1 Notations

A, B, C, D – Working state

a, b, c, d – indicates the failed state of A, B, C, D respectively.

D_1, D_2 – represent cold standby redundant D unit.

y_i/x_i – respective mean constant repair/failure rates from states A, B, C, D to the state a, b, c, d.; i=1,2,3,4

2.2 Assumptions

The repair process begins soon after a unit fails.

Failure and repairs rates for each unit are constant and statistically independent.

The standby units are of the same nature and capacity as the active units.

3. State Transitions Diagrams

The state S_2, S_6, S_{10} are the working states, S_3, S_4, S_5, S_7, S_8, S_9, S_{11}, S_{12}, S_{13}, S_{14} are failed states. Whereas, S_2 is taken as the base state.

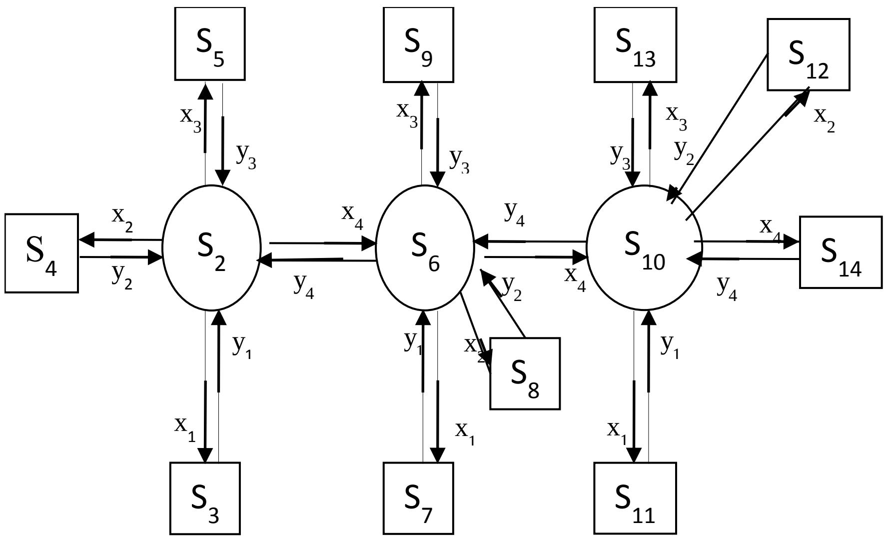

Figure 1: Transition Diagram of the system

S_2 = ABCD,	S_3 =aBCD,	S_4 =AbCD,	S_5 =ABcD,
S_6 =ABCD$_1$,	S_7 =aBCD$_1$,	S_8 =AbCD$_1$,	S_9 =ABcD$_1$,
S_{10} = ABCd$_2$,	S_{11} =aBCD$_2$,	S_{12} = AbCD$_2$,	S_{13} = ABcD$_2$,
S_{14} = ABCd			

4. Transition Probability & Mean Sojourn Times

$r_{i,j}(t)$: Probability distribution function from i to j. Li,j: Transition probability from i to j.

$L_{i,j} = r_{i,j}{*}(0)$; where * designate Laplace transform.

Table 1: Transition Probabilities

$r_{i,j}(t)$	$L_{ij} = r^*_{i,j}(0)$
$r_{2,i}(t) = x_j e^{-(x_1+x_2+x_3+x_4)t}$; i =2,3,4,5 & j = 1,2,3,4	$l_{2,i} = x_j/(x_1+x_2+x_3+x_4)$ i =2,3,4,5 & j = 1,2,3,4
$r_{3,2} = y_1 e^{-y_1 t}$	$l_{3,2} = 1$
$r_{4,2} = y_2 e^{-y_2 t}$	$l_{4,2} = 1$
$r_{5,2} = y_3 e^{-y_3 t}$	$l_{5,2} = 1$
$r_{6,2}(t) = y_4 e^{-(x_1+x_2+x_3+x_4+y_4)t}$ $r_{6,i}(t) = x_j e^{-(x_1+x_2+x_3+x_4+y_4)t}$ i =6,7,8,9 & j = 1,2,3,4	$l_{6,2} = y_4/(x_1+x_2+x_3+x_4+y_4)$ $l_{6,i} = x_j/(x_1+x_2+x_3+x_4+y_4)$ i =6,7,8,9 & j = 1,2,3,4
$r_{7,6} = y_1 e^{-y_1 t}$	$l_{7,6} = 1$
$r_{8,6} = y_2 e^{-y_2 t}$	$l_{8,6} = 1$
$r_{9,6} = y_3 e^{-y_3 t}$	$l_{9,6} = 1$
$r_{10,6}(t) = y_4 e^{-(x_1+x_2+x_3+x_4+y)t}$ $r_{10,i}(t) = x_j e^{-(x_1+x_2+x+x_4+y_4)t}$ i =10,11,12,13 & j = 1,2,3,4	$l_{10,6} = y_4/(x_1+x_2+x_3+x_4+y_4)$ $p_{10,i} = x_j/(x_1+x_2+x_3+x_4+y_4)$ i =10,11,12,13 & j = 1,2,3,4
$r_{11,10} = y_1 e^{-y_1 t}$	$l_{11,10} = 1$
$r_{12,10} = y_2 e^{-y_2 t}$	$l_{12,10} = 1$
$r_{13,10} = y_3 e^{-y_3 t}$	$l_{13,10} = 1$
$r_{14,10} = y_4 e^{-y_4 t}$	$l_{14,10} = 1$

Table 2: Mean Sojourn Times

$S_i(t)$	$\mu_i = S_i^*(0)$
$S_2(t) = e^{-(x_1+x_2+x_3+x_4)t}$	$\mu_2 = 1/(x_1+x_2+x_3+x_4)$
$S_3(t) = e^{-y_1 t}$	$\mu_3 = 1/y_1$
$S_4(t) = e^{-y_2 t}$	$\mu_4 = 1/y_2$
$S_5(t) = e^{-y_3 t}$	$\mu_5 = 1/y_3$
$S_6(t) = e^{-(x_1+x_2+x_3+x_4+y_4)t}$	$\mu_6 = 1/(x_1+x_2+x_3+x_4+y_4)$

$S_7(t) = e^{-y_1 t}$	$\mu_7 = 1/y_1$
$S_8(t) = e^{-y_2 t}$	$\mu_8 = 1/y_2$
$S_9(t) = e^{-y_3 t}$	$\mu_9 = 1/y_3$
$S_{10}(t) = e^{-(x_1+x_2+x_3+x_4+y_4)t}$	$\mu_{10} = 1/(x_1+x_2+x_3+x_4+y_4)$
$S_{11}(t) = e^{-y_1 t}$	$\mu_{11} = 1/y_1$
$S_{12}(t) = e^{-y_2 t}$	$\mu_{12} = 1/y_2$
$S_{13}(t) = e^{-y_3 t}$	$\mu_{13} = 1/y_3$
$S_{14}(t) = e^{-y_4 t}$	$\mu_{14} = 1/y_4$

5. Evaluation of Path Probabilities:

Applying RPGT and by ‘2’ as initial-state offramework as under: The transition probability factors of all accessible states from base state ‘ξ’ = ‘10’ are:

$V_{2,2} = 1$

$V_{2,i} = (2, i) = l_{2,i}$

where i = 3, 4, 5

$V_{2,6} = l_{2,6}/(1-l_{6,7}\,l_{7,6})\,(1-l_{6,8}\,l_{8,6})\,(1-l_{6,9}\,l_{9,6})\{(1-l_{6,10}\,l_{10,6})/(1-l_{10,11}\,l_{11,10})(1-l_{10,12}\,l_{12,10})\,(1-l_{10,13}\,l_{13,10})\,(1-l_{10,14}\,l_{14,10})\}$

$V_{2,i} = l_{2,6}\,l_{6,i}/(1-l_{6,7}\,l_{6,7})(1-l_{6,8}\,l_{8,6})\,(1-l_{6,9}\,l_{9,6})\{(1-l_{6,10}\,l_{10,6})/(1-l_{10,11}\,l_{11,10})(1-l_{10,12}\,l_{12,10})\,(1-l_{10,13}\,l_{13,10})\,(1-l_{10,14}\,l_{14,10})\}$

i = 7, 8, 9

$V_{2,10} = l_{2,6}\,l_{6,10}/(1-l_{6,7}\,l_{7,6})\,(1-l_{6,8}\,l_{8,6})\,(1-l_{6,9}\,l_{9,6})\,(1-l_{10,11}\,l_{11,10})\,(1-l_{10,12}\,l_{12,10})(1-l_{10,13}\,l_{13,10})\,(1-l_{10,14}\,l_{14,10})\,\{(1-l_{6,10}\,l_{10,6})/(1-l_{10,11}\,l_{11,10})\,(1-l_{10,12}\,l_{12,10})(1-l_{10,13}\,l_{13,10})(1-l_{10,14}\,l_{14,10})\}$

$V_{2,i} = l_{2,6}\,l_{6,10}\,l_{10,i}/(1-l_{6,7}\,l_{7,6})\,(1-l_{6,8}\,l_{8,6})\,(1-l_{6,9}\,l_{9,6})\,(1-l_{10,11}\,l_{11,10})\,(1-l_{10,12}\,l_{12,10})(1-l_{10,13}\,l_{13,10})\,(1-l_{10,14}\,l_{14,10})\,\{(1-l_{6,10}\,l_{10,6})\,/\,(1-l_{10,11}\,l_{11,10})\,(1-l_{10,12}\,l_{12,10})\,(1-l_{10,13}\,l_{13,10})\,(1-l_{10,14}\,l_{14,10})\}$

i = 11,12,13,14

Probabilities from state ‘10’ to dissimilar vertices are assumed as

$V_{10,2} = l_{10,6}\,l_{10,2}/\,(1-l_{6,7}\,l_{7,6})\,(1-l_{6,8}\,l_{8,6})\,(1-l_{6,9}\,l_{9,6})\,(1-l_{2,3}\,l_{3,2})\,(1-l_{2,4}\,l_{4,2})\,(1-l_{2,5}\,l_{5,2})\,\{(1-l_{6,2}l_{2,6})/\,(1-l_{2,3}\,l_{3,2})\,(1-l_{2,4}\,l_{4,2})\,(1-l_{2,5}\,l_{5,2})\}$

$V_{10,i} = l_{10,6}\,l_{10,2}\,l_{2,i}/(1-l_{6,7}\,l_{7,6})\,(1-l_{6,8}\,l_{8,6})\,(1-l_{6,9}\,l_{9,6})\,(1-l_{2,3}l_{3,2})(1-l_{2,4}\,l_{4,2})(1-l_{2,5}l_{5,2})\,\{(1-l_{6,2}\,l_{2,6})/(1-l_{2,3}\,l_{3,2})\,(1-l_{2,4}\,l_{4,2})\,(1-l_{2,5}\,l_{5,2})\}$

i = 2, 3, 4

$V_{10, 6} = l_{10, 6}/(1- l_{6, 7} l_{7, 6}) (1- l_{6, 8} l_{8, 6}) (1- l_{6, 9} l_{9, 6}) \{(1- l_{6, 2} l_{2, 6})/(1- l_{2, 3} l_{3, 2})(1- l_{2, 4} l_{4, 2})(1- l_{2, 5} l_{5, 2})\}$

$V_{10, i} = l_{10, 6} l_{6, i}/(1- l_{6, 7} l_{7, 6}) (1- l_{6, 8} l_{8, 6}) (1- l_{6, 9} l_{9, 6}) \{(1- l_{6, 2} l_{2, 6})/(1- l_{2, 3} l_{3, 2})(1- l_{2, 4} l_{4, 2}) (1- l_{2, 5} l_{5, 2})\}$

$i = 6, 7, 8$

$V_{10, 10} = 1$

$V_{10, i} = l_{10, i}$; $i = 10,11, 12, 13$

6. Measures of plant effectiveness

6.1 Mean time to system failure(T_0): Regenerative un-failed states to which the frameworkcontainer transit(initial state '2'), afore entering any unsuccessful state are: 'i' = 2, 6, 10.

$T_0 = (V_{2, 2}\, \mu_2 + V_{2, 6}\, \mu_6 + V_{2, 10}\, \mu_{10})/\{1- V(2, 6, 2)\}(1-l_{2, 6} l_{6, 2})$

6.2 Availability of the system(A_0): Regenerative states at which the framework is obtainable are 'j' = 2,6,10&reformative states are 'i' = 2 to 14.

$A_0 = \left[\sum_j V_{\xi,j}\, , f_j\, , \mu_j\right] \div \left[\sum_i V_{\xi,i}\, , f_j\, , \mu_i^1\right]$

$A_0 = (V_{10, 2}\, \mu_2 + V_{10, 6}\, \mu_6 + V_{10, 10}\, \mu_{10})/D$

Where $D = V_{2, I}\, \mu_i$; $2 \leq i \leq 14$

6.3 Busy period of the server (B_0): Regenerative states where attendant is hectic are j = 3 to 14,reformative states are 'i' = 2 to 14.

$B_0 = \left[\sum_j V_{\xi,j}\, , n_j\right] \div \left[\sum_i V_{\xi,i}\, , \mu_i^1\right]$

$B_0 = (V_{2,j}\mu_j)/D$

$3 \leq j \leq 14$

6.4 Expected number of the server visits (V_0): Regenerative states where repairman visit is j = 3 to 14 reformative states are i = 2 to 14.

$V_0 = \left[\sum_j V_{\xi,j}\right] \div \left[\sum_i V_{\xi,i}\, , \mu_i^1\right]$

$V_0 = (V_{2,j})/ D$

$3 \leq j \leq 14.$

7. Profit function of the system

Profit function of the system can be done by utilizing the profit function

$P_0 = E_1A_0 - E_2B_0 - E_3V_0$

Where;

$E_1 = 200$

$E_2 = 50$

$E_3 = 100$

Table 3: Profit function of the system

	y = .50	y = .60	y = .70
x = .10	179	230	282
x = .20	68	115	159
x = .30	39	85	123

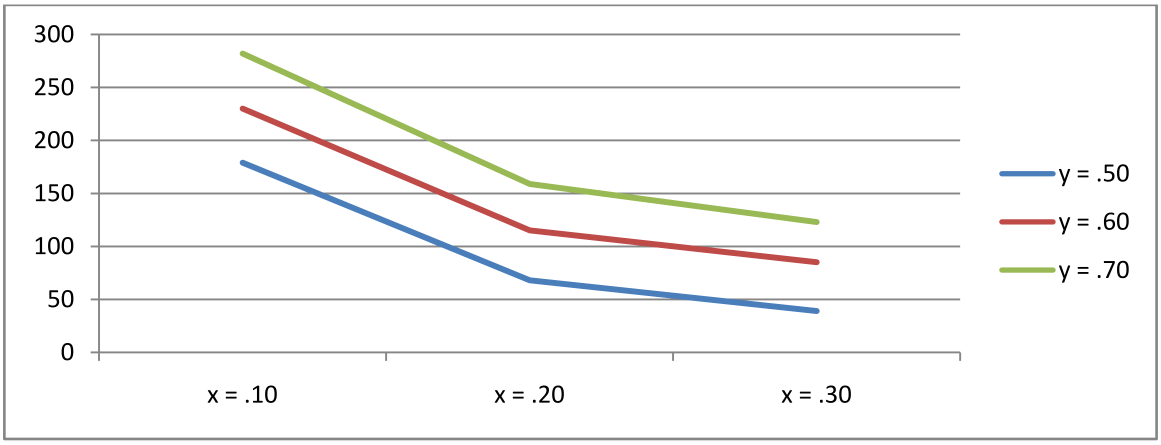

Fig. 2: Profit function of the system

8. Conclusion:

The organization of small and large different sub-units is precise complex but different human beings are continuously interested in finding the extra efforts for example expanding the repair rate of sub-unit additional cost would have to be incurred. Hence the stake holders will be involved to see the expanding in proportional profit, helpfulness, rise in market share. Observance the ideal values of the framework parameters at the specific bench mark stake holders can decide apprehend whether to go for efficient repairman having higher repair rate utilizing RPGT. Organization parameters are assessed simply in comparison to other techniques. As failure rates are outside the control of stake holders, consequently only the repair rates of the sub-unit can be better. The table 3 and figure 2, it is shows that when failure rates increases the profit function decrease and repair rates increases then the profit functions increases.

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