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RELIABILITY AND PROFIT ANALYSIS OF REPAIRABLE EDIBLE OIL PLANT

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Abstract

In daily life, edible oil is necessary for making food to human. This paper described the reliability, availability and profit values of the edible oil plant by using regenerative point graphical technique. Generally, it contains four units such that bleacher (B), deodorizer (D), thermo fluid boiler (C) and pressured filter (A). The whole refinery plant work properly when all units work properly. Only unit (A) is in partially failed state as well as complete failed state and other remaining units are in complete failed state. The system works when unit is in operative state or partially failed state. The system fails when one unit completely fails. A technician is always available to repair the failed unit. In this paper, the failure time and repair time follows general distributions. The regenerative point graphical technique with stochastic process is used to explore the reliability measures such that mean time to system failure, availability of the system, and profit values.

Keywords: Base state, oil refinery, reliability, availability and profit values.

I. Introduction

Manufacturers must constantly innovate their products to keep up with the rising demand for their products, which is made feasible by optimizing their manufacturing processes. The MTSF, availability and profitability of the edible oil plant with priority in repair are discussed in this study by utilizing the regenerating point graphical technique under specific circumstances. Many researchers threw light on the various industrial systems using different methods. Balagurusamy [2] described the terms related to the systems meantime, failure, repair, redundancy, maintainability, and availability measures. Gupta et al. [5] examined the single unit system using base state and regenerative point graphical technique. The reliability analysis of a one-unit system with finite vacations was examined by Liu and Liu [13]. Aggarwal et al. [1] threw light on the behaviour of refining system of a sugar plant under serial processing with regenerative point graphical technique. Sadeghi and Roghanian [15] analyzed the reliability, availability and profit values of two unit warm standby system under imperfect switch. Kumar et al. [11] examined the availability and profit values of bread manufacturing system with regenerative point graphical technique. Kumar et al. [12] described the performance of industrial system under multistate failure. Thori and Goel [16] evaluated the stochastic behaviour of edible oil refinery.

Barak et al. [3] examined the reliability characteristics of milk plant using regenerative point graphical technique. Barak et al. [4] threw light on the performance of two unit cold standby system with availability of technician and refreshment approach under semi markov process and regenerative point technique. Kumar and Sharma [6] evaluated the two unit cold standby system under refreshment facility. Kumar et al. [8] descried the performance and reliability measures of cold standby computer system under software upgrade and load recovery facility. Kumar et al. [9] analyzed the computer system hardware and software performance using Weibull distribution and regenerative point technique. Kumar et al. [10] examined the reliability measures of a two unit cold standby system subject to inspection before repair. Kumar and Sharma [7] described the reliability characteristics of two unit cold standby system with reboot and refreshment facilities. Rahul et al. [14] discussed on the availability and profit values of juice plant with regenerative point graphical technique.

II. System Assumptions

A refinery system is the combination of subunits and every subunit has its significant values in the refinery plant. To describe the edible oil refinery, there are following assumptions

- The edible oil refinery consists of four distinct units *A*, *B*, *C* and *D*.
- It is considered that units *A* is in a complete failed state through partial failure mode but unit *B*, *C* and *D* are in complete failed state.
- Unit *A* has pressured filters, and unit *B* has bleaching.
- Unit *C* has thermo fluid boiler, and unit D has deodorizer.
- A technician is always available with the system.
- Failure time and repair time are generally distributed and are independent.
- The unit works just like a brand-new one after repair.

III. System Notations

To explain the edible oil refinery, there are following notations

$i \xrightarrow{Sr} j$	r^{th} directed simple path from state '*i*' to state '*j*' where '*r*' takes the positive integral values for different directions from state '*i*' to state '*j*'.
$\xi \xrightarrow{sff} i$	A directed simple failure free path from state ξ to state '*i*'.
$m-cycle$	A circuit (may be formed through regenerative or non regenerative / failed state) whose terminals are at the regenerative state '*m*'.
$m-\overline{cycle}$	A circuit (may be formed through the unfailed regenerative or non regenerative state) whose terminals are at the regenerative '*m*' state.
$q_{ij}(t)$	PDF of the first passage time from a regenerative state *i* to a regenerative state state *j* or to a failed state *j* without visiting any other regenerative state in (0,1].
$U_{k,k}$	Probability factor of the state '*k*' reachable from the terminal state '*k*' of '*k*' cycle.
$U_{\overline{k,k}}$	The probability factor of state '*k*' reachable from the terminal state '*k*' of $k\ \overline{cycle}$.
μ_i	Mean sojourn time spent in the state '*i*' before visiting any other states.
μ_i'	Total unconditional time spent before transiting to any other regenerative state while the system entered regenerative state '*i*' at t=0.
ξ	Base state of the system.
f_j	Fuzziness measure of the *j*-state.
η_i	Expected waiting time spent while doing a job given that the system entered to the regenerative state '*i*' at t=0.
$A/\overline{A}/a$	The unit is in the operative state/reduced state/failed state.
B/b	The unit is in the operative state/failed state.

C / c	The unit is in the operative state/failed state.
D / d	The unit is in the operative state/failed state.
λ_1 / λ_5	Fixed partial failure rate/complete failure rate of the unit A respectively.
λ_2 , λ_6	Fixed complete failure rate of the unit B.
λ_3 , λ_7	Fixed complete failure rate of the unit C.
λ_4 , λ_8	Fixed complete failure rate of the unit D.
w_1 , w_5	Fixed repair rate of the partially failed/complete failed unit A respectively.
w_2 , w_6	Fixed repair rate of unit B after the complete failure.
w_3 , w_7	Fixed repair rate of unit C after the complete failure.
w_4 , w_8	Fixed repair rate of unit D after the complete failure.
○/ ⬭/ ▭	Upstate/ reduced state/ failed state.

IV. Circuits Descriptions

Using the transition diagram, primary, secondary and tertiary circuits are calculated and used to find the base state of the system such that

Table 1: *Circuit Descriptions*

i	(C1)	(C2)	(C3)
0	(0,1,0), (0,2,0), (0,3,0), (0,4,0), (0,1,5,0)	(1,6,1), (1,7,1), (1,8,1)	Nil
1	(1,0,1), (1,6,1), (1,7,1), (1,8,1), (1,5,0,1)	(0,2,0), (0,3,0), (0,4,0)	Nil
2	(2,0,2)	(0,1,0), (0,3,0), (0,4,0)	Nil
3	(3,0,3)	(0,1,0), (0,2,0), (0,4,0)	Nil
4	(4,0,4)	(0,1,0), (0,2,0), (0,3,0)	Nil
5	(5,0,1,5)	(0,1,0), (0,3,0), (0,4,0), (1,6,1), (1,7,1), (1,8,1)	Nil
6	(6,1,6)	(1,0,1), (1,7,1), (1,8,1), (1,5,0,1)	Nil
7	(7,1,7)	(1,0,1), (1,6,1), (1,8,1), (1,5,0,1)	Nil
8	(8,1,8)	(1,0,1), (1,6,1), (1,7,1), (1,5,0,1)	Nil

where, $S_0 = ABCD$, $S_1 = \bar{A}BCD$, $S_2 = AbCD$, $S_3 = ABcD$

$S_4 = ABCd$, $S_5 = aBCD$, $S_6 = \bar{A}bCD$, $S_7 = ABcD$, $S_8 = \bar{A}BCd$

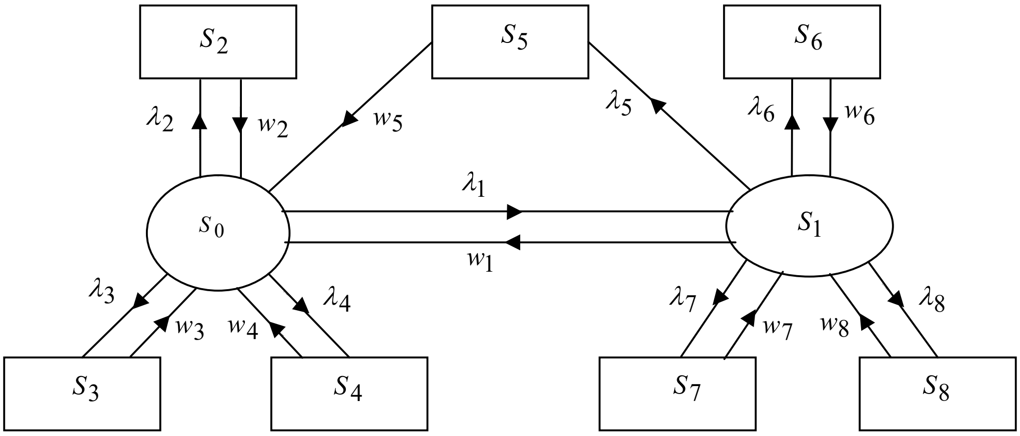

Figure 1 *State Transition Diagram*

V. Transition Probabilities

There are following transition probabilities

$p_{0,1} = \lambda_1 /(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4)$, $p_{0,2} = \lambda_2 /(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4)$

$p_{0,3} = \lambda_3 /(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4)$, $p_{0,4} = \lambda_4 /(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4)$

$p_{1,0} = w_1 /(w_1 + \lambda_5 + \lambda_6 + \lambda_7 + \lambda_8)$, $p_{1,5} = \lambda_5 /(w_1 + \lambda_5 + \lambda_6 + \lambda_7 + \lambda_8)$

$p_{1,6} = \lambda_6 /(w_1 + \lambda_5 + \lambda_6 + \lambda_7 + \lambda_8)$, $p_{1,7} = \lambda_5 /(w_1 + \lambda_5 + \lambda_6 + \lambda_7 + \lambda_8)$

$p_{1,8} = \lambda_8 /(w_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5)$, $p_{2,0} = p_{3,0} = p_{4,0} = p_{5,0} = p_{6,1} = p_{7,1} = p_{8,1} = 1$ (1)

It is verified that

$p_{0,1} + p_{0,2} + p_{0,3} + p_{0,4} = 1$, $p_{1,0} + p_{1,5} + p_{1,6} + p_{1,7} + p_{1,8} = 1$

VI. Mean Sojourn Time

For the particular state, it becomes

$\mu_0 = 1/(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4)$, $\mu_1 = 1/(w_1 + \lambda_5 + \lambda_6 + \lambda_7 + \lambda_8)$, $\mu_2 = 1/(w_2)$, $\mu_3 = 1/(w_3)$

$\mu_4 = 1/(w_4)$, $\mu_5 = 1/(w_5)$, $\mu_6 = 1/(w_6)$, $\mu_7 = 1/(w_7)$, $\mu_8 = 1/(w_8)$ (2)

VII. Evaluation of Parameters

Using the circuit table, '0' is used as the base state to calculate the reliability measures with the regenerative point graphical technique. The probability factors of all the reachable states from the base state '0' are given below

$$U_{0,0} = 1,\ U_{0,1} = \frac{\mu_1 (w_1 + \lambda_5 + \lambda_6 + \lambda_7 + \lambda_8)^3}{\begin{bmatrix}(w_1 + \lambda_2 + \lambda_3 + \lambda_4)(w_1 + \lambda_3 + \lambda_4 + \lambda_5)\times \\ (w_1 + \lambda_2 + \lambda_4 + \lambda_5)(\lambda_2 + \lambda_3 + \lambda_4 + \lambda_5)\end{bmatrix}}$$

$U_{0,2} = \lambda_2 /(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4)$, $U_{0,3} = \lambda_3 /(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4)$, $U_{0,4} = \lambda_4 /(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4)$

$$U_{0,5}=\frac{\mu_5\lambda_1(w_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5)^2}{\begin{bmatrix}(w_1+\lambda_2+\lambda_3+\lambda_4)(w_1+\lambda_3+\lambda_4+\lambda_5)\times\\(w_1+\lambda_2+\lambda_4+\lambda_5)(\lambda_2+\lambda_3+\lambda_4+\lambda_5)\end{bmatrix}}$$

$$U_{0,6}=\frac{\mu_6\lambda_1(w_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5)^2}{\begin{bmatrix}(w_1+\lambda_2+\lambda_3+\lambda_4)(w_1+\lambda_3+\lambda_4+\lambda_5)\times\\(w_1+\lambda_2+\lambda_4+\lambda_5)(\lambda_2+\lambda_3+\lambda_4+\lambda_5)\end{bmatrix}}$$

$$U_{0,7}=\frac{\mu_7\lambda_1(w_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5)^2}{\begin{bmatrix}(w_1+\lambda_2+\lambda_3+\lambda_4)(w_1+\lambda_3+\lambda_4+\lambda_5)\times\\(w_1+\lambda_2+\lambda_4+\lambda_5)(\lambda_2+\lambda_3+\lambda_4+\lambda_5)\end{bmatrix}}$$

$$U_{0,8}=\frac{\mu_8\lambda_1(w_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5)^2}{\begin{bmatrix}(w_1+\lambda_2+\lambda_3+\lambda_4)(w_1+\lambda_3+\lambda_4+\lambda_5)\times\\(w_1+\lambda_2+\lambda_4+\lambda_5)(\lambda_2+\lambda_3+\lambda_4+\lambda_5)\end{bmatrix}}$$

I. Mean Time to System Failure

The regenerative un-failed states (i=0, 1) to which the system can transit (with initial state 0) before entering to any failed state (using base state ξ=0) then MTSF becomes

$$T_0=\left[\sum_{i=0}^{1} Sr\left\{\frac{\left\{pr\left(0\xrightarrow{Sr(sff)} i\right)\right\}.\mu_i}{\Pi_{k_1\neq 0}\left\{1-V_{\overline{k_1k_1}}\right\}}\right\}\right]\div\left[1-\sum Sr\left\{\frac{\left\{pr\left(0\xrightarrow{Sr(sff)} 0\right)\right\}}{\Pi_{k_2\neq 0}\left\{1-V_{\overline{k_2k_2}}\right\}}\right\}\right]$$

$$T_0=\frac{U_{0,0}\mu_0+U_{0,1}\mu_1}{[1-(1,0,1)]} \tag{3}$$

II. Availability of the system

The system is available for use at regenerative states j=0, 1 with ξ=0 then the availability of system is defined as

$$A_0=\left[\sum_{j=0}^{1} Sr\left\{\frac{\left\{pr\left(0\xrightarrow{Sr} j\right)\right\}.f_j.\mu_j}{\Pi_{k_1\neq 0}\left\{1-V_{\overline{k_1k_1}}\right\}}\right\}\right]\div\left[\sum_{i=0}^{8} Sr\left\{\frac{\left\{pr\left(0\xrightarrow{Sr} i\right)\right\}.\mu_i'}{\Pi_{k_2\neq 0}\left\{1-V_{\overline{k_2k_2}}\right\}}\right\}\right]$$

$$A_0=\frac{U_{0,0}\mu_0+U_{0,1}\mu_1}{\begin{bmatrix}U_{0,0}\mu_0+U_{0,1}\mu_1+U_{0,2}\mu_2+U_{0,3}\mu_3+U_{0,4}\mu_4\\+U_{0,5}\mu_5+U_{0,6}\mu_6+U_{0,7}\mu_7+U_{0,8}\mu_8\end{bmatrix}} \tag{4}$$

III. Busy Period of the Technician

A technician is always available with the system to repair the failed unit. The technician is busy due to repair of the failed unit at regenerative states j= 1, 2, 3, 4, 5, 6, 7, 8 with ξ = 0 then the fraction of time for which the technician remains busy is defined as

$$B_0=\left[\sum_{j=1}^{8} Sr\left\{\frac{\left\{pr\left(0\xrightarrow{Sr} j\right)\right\}.\eta_j}{\Pi_{k_1\neq 0}\left\{1-V_{\overline{k_1k_1}}\right\}}\right\}\right]\div\left[\sum_{i=0}^{8} Sr\left\{\frac{\left\{pr\left(0\xrightarrow{Sr} i\right)\right\}.\mu_i'}{\Pi_{k_2\neq 0}\left\{1-V_{\overline{k_2k_2}}\right\}}\right\}\right]$$

$$B_0 = \frac{\begin{bmatrix} U_{0,1}\mu_1 + U_{0,2}\mu_2 + U_{0,3}\mu_3 + U_{0,4}\mu_4 \\ + U_{0,5}\mu_5 + U_{0,6}\mu_6 + U_{0,7}\mu_7 + U_{0,8}\mu_8 \end{bmatrix}}{\begin{bmatrix} U_{0,0}\mu_0 + U_{0,1}\mu_1 + U_{0,2}\mu_2 + U_{0,3}\mu_3 + U_{0,4}\mu_4 \\ + U_{0,5}\mu_5 + U_{0,6}\mu_6 + U_{0,7}\mu_7 + U_{0,8}\mu_8 \end{bmatrix}} \tag{5}$$

IV. Estimated number of visits made by the Technician

The technician visits at regenerative states *j*= 1 with ξ=0 then the number of visits by the technician is defined as

$$V_0 = \left[\sum_{j=1} Sr \left\{ \frac{\left\{ pr\,(0 \xrightarrow{Sr} j) \right\}}{\Pi_{k_1 \neq 0} \left\{ 1 - V_{\overline{k_1 k_1}} \right\}} \right\} \right] \div \left[\sum_{i=0}^{8} Sr \left\{ \frac{\left\{ pr\,(0 \xrightarrow{Sr} i) \right\} . \mu_i'}{\Pi_{k_2 \neq 0} \left\{ 1 - V_{\overline{k_2 k_2}} \right\}} \right\} \right]$$

$$V_0 = \frac{\left[U_{0,1}\mu_1 \right]}{\begin{bmatrix} U_{0,0}\mu_0 + U_{0,1}\mu_1 + U_{0,2}\mu_2 + U_{0,3}\mu_3 + U_{0,4}\mu_4 \\ + U_{0,5}\mu_5 + U_{0,6}\mu_6 + U_{0,7}\mu_7 + U_{0,8}\mu_8 \end{bmatrix}} \tag{6}$$

V. Profit Analysis

The profit function may be used to do a profit analysis of the system and it is given by

$$P = E_0 A_0 - E_1 B_0 - E_2 V_0 \tag{7}$$

where, $E_0 = 2500$ (Revenue per unit uptime of the system)

$E_1 = 500$ (Cost per unit time for which technician is busy due to repair)

$E_2 = 200$ (Cost per visit of the technician)

VIII. Discussion

It is assumed that all $\lambda_i = \lambda$ for *i*=1, 2, 3, 4, 5, 6, 7, 8 and $w_j = w$ for *j*=1, 2, 3, 4, 5, 6, 7, 8. Tables 2, 3 and 4 describe the nature of mean time to system failure, availability and profit values of the edible

Table 2: *MTSF vs. Repair Rate* (*w*)

w ↓	λ=0.3	λ=0.4	λ=0.5
0.5	3.545455	3.244275	3.040826
0.55	3.588589	3.276736	3.079858
0.6	3.630952	3.308458	3.118812
0.65	3.672566	3.339483	3.157248
0.7	3.713458	3.36983	3.195122
0.75	3.753623	3.399519	3.232446
0.8	3.793103	3.428571	3.269231
0.85	3.831909	3.457008	3.305489
0.9	3.870056	3.484848	3.341232
0.95	3.907563	3.512111	3.376471

Table 3: *Availability vs. Repair Rate* (w)

w ↓	λ=0.3	λ=0.4	λ=0.5
0.5	0.629837	0.609587	0.547732
0.55	0.634798	0.614607	0.552793
0.6	0.639628	0.619499	0.557741
0.65	0.644332	0.624269	0.562582
0.7	0.648915	0.628925	0.567318
0.75	0.653381	0.633458	0.571952
0.8	0.657734	0.637887	0.576488
0.85	0.661985	0.642209	0.580929
0.9	0.666122	0.646438	0.585278
0.95	0.670164	0.650552	0.589538

Table 4: *Profit vs. Repair Rate* (w)

w ↓	λ=0.3	λ=0.4	λ=0.5
0.5	2456.69	2399.61	2035.15
0.55	2485.35	2429.18	2064.97
0.6	2513.15	2458.02	2094.16
0.65	2540.26	2486.16	2122.65
0.7	2566.68	2513.53	2150.56
0.75	2592.43	2540.28	2177.86
0.8	2617.54	2566.36	2204.59
0.85	2642.02	2591.83	2230.76
0.9	2665.89	2616.76	2256.38
0.95	2689.22	2640.98	2281.48

oil refinery having an increasing trend corresponding to increment in repair rate (w). In these tables, the values of parameters change such that λ=0.3, 0.4, 0.5 and w=0.5, 0.55, 0.6, 0.65, 0.7, 0.75, 0.8, 0.85, 0.9, 0.95 respectively. When λ=0.3 changes into 0.4, 0.5 then MTSF, availability and profit values have decreasing trends.

IX. Conclusion

The performance of the edible oil refinery is discussed using the regenerative point graphical technique. The above tables explore that when the repair rate increases then the MTSF, availability and profit values also increase but when the failure rate increases then the MTSF, availability and profit values decrease. It is clear that RPGT is helpful for industries to analyze the behaviour of the products and components of a system.

X. Future Scope

It is observed that the role of the regenerative point graphical technique for the edible oil will be beneficial and also used by the management, manufacturers and the persons engaged in reliability engineering and working on analyzing the nature and performance analysis of the system like soft drink, paper industry, etc.

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