COMPARATIVE STUDY OF REPAIRABLE JUICE PLANTS USING RPGT

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Abstract

In this paper, comparative study of repairable juice plants is analyzed by using regenerative point graphical technique. Generally, juice contains calcium, vitamin, iron, etc. to give the refresh tests. There are multiple steps to store the juice at large levels such as storing, grinding, pasteurization, etc. In this paper, the performance and reliability measures of existing juice plant-I are discussed and compared with juice plane-II. Both juice plants have three distinct units. Unit A has washing and storage tank, unit B has grinding, blending, evaporation and pasteurization, and unit C has bottling, labeling and packing units. If any unit partially fails then the system works to a limited extent. A technician is always available to repair the failed unit. The system fails when one unit completely fails. In this paper, the failure time and repair time follow general distributions. The regenerative point graphical technique is used to explore the comparison of reliability measures.

Keywords: Base state, juice plant, availability, and profit values.

I. Introduction

Every industrialist wants to maximize their manufacturing processes to meet customer requests. This study uses the regenerating point graphical technique with semi Markov process to explore the mean time to system failure, availability and profit values of a juice plant with repair facility. Here, existing juice plant-I is compared with the juice plant-II discussed by Rahul and his coauthors. Balagurusamy [2] described the terms related to the system's meantime, failure, repair, redundancy, maintainability, availability and profit function. Wang et al. [19] analyzed the reliability and sensitivity of two unit system under repair conditions. Srinivasan and Subramanian [17] discussed on the reliability measures of warm standby system under repair facility. Teng et al. [18] discussed on the software and hardware system reliability and availability using stochastic process. Bhatti et al. [5] inspected the availability and profit values of the two unit system with two type of failure using discrete distribution.

Jyh-Bin et al. [6] threw light on the reliability parameters of repairable system using standby repair facility and reboot delay approach. Yuang and Meng [20] analyzed the reliability of two unit repairable redundant system under priority in use. The reliability analysis of a one-unit system with finite vacations was examined by Liu and Liu [13]. Kumar and Goel [12] evaluated the behaviour of two unit cold standby system under general distribution. Aggarwal et al. [1]

described the performance of serial process in refinery system of a sugar plant using regenerative point technique and semi-Markov process. Sadeghi and Roghanian [16] described the reliability parameters of a repairable system under imperfect switching. Barak et al. [3] evaluated the reliability, availability and profit values of repairable milk plant. Barak et al. [4] discussed on the role of refreshment in repairable two unit system. Kumar et al. [9] evaluated the performance of two unit cold standby system subject to software upgrade and load recovery facility. Kumar et al. [10] described the two unit computer system under hardware repair and software upgrade facility. Kumar et al. [11] analyzed the cold standby system subject to refreshment facility. Kumar and Sharma [7] analyzed the availability and profit function of two unit cold standby system using regenerative point technique. Kumar and Sharma [8] examined the reliability measures of two unit cold standby system subject to reboot delay facility. Reddy et al. [15] analyzed the reliability measures of utensil industry under repair facility. Rahul et al. [14] described the reliability measures of juice plants using regenerative point technique.

II. System Assumptions

To describe the juice plant-I, there are following assumptions
- The juice plant consists of three distinct units *A*, *B* and *C*.
- It is considered that units *A*, *B* and *C* may be in a complete failed state through partial failure mode.
- Unit *A* has washing and storage tank.
- Unit *B* has grinding, blending, evaporation and pasteurization.
- Unit *C* has bottling, labeling and packing units.
- Failure rate and repair rate are generally distributed and are independent.
- The repaired unit functions just like a brand-new one.

To describe the juice plant-II, all assumptions are same as juice plant-I with difference in
- It is considered that units *A* and *B* may be in a complete failed state through partial failure mode but unit *C* is in only partially failed state.

III. System Notations

To explain the juice plants, there are following notations

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$i \xrightarrow{Sr} j$	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.
$U_{k,k}$	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 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.
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 first unit is in the operative state/reduced state/failed state.

$B/\overline{B}/b$	The second unit is in the operative state/reduced state/failed state.
$C/\overline{C}/c$	The third unit is in the operative state/reduced state/failed state.
$\lambda_1, \lambda_2, \lambda_3$	Fixed partial failure rate of the unit A/B/C respectively.
$\lambda_4, \lambda_5, \lambda_6$	Fixed complete failure rate of the unit A/B/C respectively.
w_1, w_2, w_3	Fixed repair rate of the unit A/B/C after partial failure respectively.
w_4, w_5, w_6	Fixed repair rate of unit A/B/C after the complete failure respectively.
$\bigcirc\;\ominus\;\square$	Upstate/ reduced state/ failed state.

IV. Circuits Descriptions of Juice Plant-I

Primary, secondary and tertiary circuits are used to find the base state such that

Table 1: *Circuit Descriptions*

i	(C1)	(C2)	(C3)
0	(0,1,0), (0,2,0), (0,3,0) (0,1,4,0), (0,2,5,0), (0,3,6,0)	Nil	Nil
1	(1,0,1)	(0,2,0), (0,3,0)	Nil
2	(2,0,2)	(0,1,0), (0,3,0)	Nil
3	(3,0,3)	(0,1,0), (0,2,0)	Nil
4	(4,0,1,4)	(0,1,0), (0,2,0) (0,3,0), (1,0,1)	(2,0,2), (3,0,3)
5	(5,0,2,5)	(0,1,0), (0,2,0) (0,3,0), (2,0,2)	(1,0,1), (3,0,3)
6	(6,0,3,6)	(0,1,0), (0,2,0) (0,3,0), (3,0,3)	(1,0,1), (2,0,2)
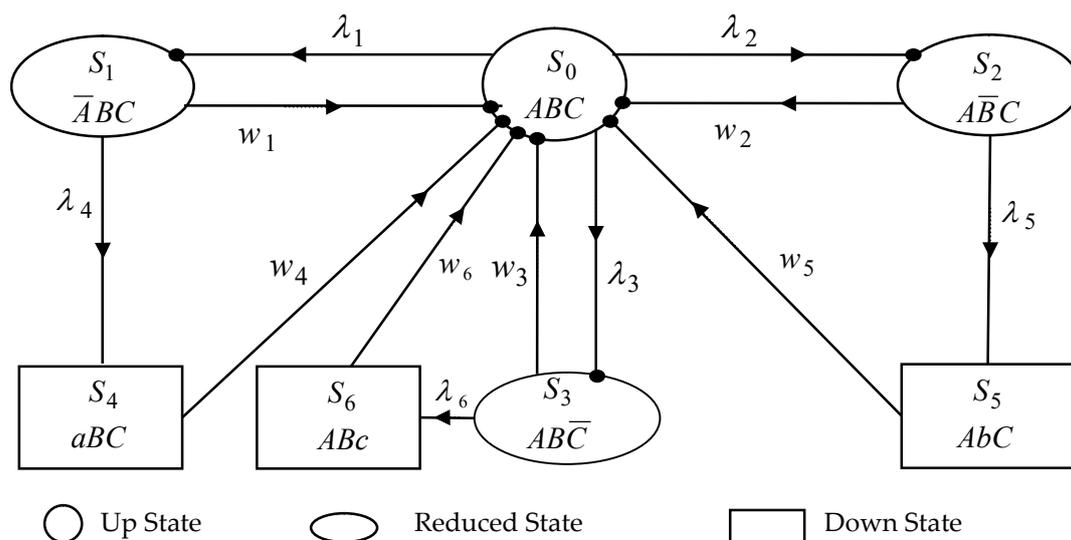
Figure 1 *State Transition Diagram of Juice Plant-I*

where, $S_0 = ABC$, $S_1 = \overline{A}BC$, $S_2 = A\overline{B}C$, $S_3 = AB\overline{C}$, $S_4 = aBC$, $S_5 = AbC$, $S_6 = ABc$

V. Transition Probabilities

There are following transition probabilities

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

$p_{0,3} = \lambda_3 / (\lambda_1 + \lambda_2 + \lambda_3)$, $p_{1,0} = w_1 / (w_1 + \lambda_4)$,

$p_{2,0} = w_2 / (w_2 + \lambda_5)$, $p_{2,5} = \lambda_5 / (w_2 + \lambda_5)$,

$p_{3,0} = w_3 / (w_3 + \lambda_6)$, $p_{3,6} = \lambda_6 / (w_3 + \lambda_6)$

$p_{4,0} = p_{5,0} = p_{6,0} = 1$ (1)

It has been conclusively established that

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

VI. Mean Sojourn Time

For the particular state, it becomes

$\mu_0 = 1/(\lambda_1 + \lambda_2 + \lambda_3)$, $\mu_1 = 1/(w_1 + \lambda_4)$,

$\mu_2 = 1/(w_2 + \lambda_5)$, $\mu_3 = 1/(w_3 + \lambda_6)$,

$\mu_4(t) = 1/(w_4)$, $\mu_5 = 1/(w_5)$, $\mu_6 = 1/(w_6)$ (2)

VII. Evaluation of Parameters

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

$U_{0,0} = (0,1,0) + (0,2,0) + (0,3,0) = 1$, $U_{0,1} = \dfrac{\lambda_1}{\lambda_1 + \lambda_2 + \lambda_3}$, $U_{0,2} = \dfrac{\lambda_2}{\lambda_1 + \lambda_2 + +\lambda_3}$

$U_{0,3} = \dfrac{\lambda_3}{(\lambda_1 + \lambda_2 + \lambda_3)}$, $U_{0,4} = \dfrac{\lambda_1 \lambda_4}{(\lambda_1 + \lambda_2 + \lambda_3)(w_1 + \lambda_4)}$

$U_{0,5} = \dfrac{\lambda_2 \lambda_5}{(\lambda_1 + \lambda_2 + \lambda_3)(w_2 + \lambda_5)}$, $U_{0,6} = \dfrac{\lambda_3 \lambda_6}{(\lambda_1 + \lambda_2 + \lambda_3)(w_3 + \lambda_6)}$

I. Mean Time to System Failure

The regenerative un-failed states (i=0, 1, 2, 3) to which the system can transit (with initial state 0) before entering to any failed state (using base state ξ=0) then MTSF becomes

$$T_0 = \left[\sum_{i=0}^{3} Sr \left\{ \frac{\left\{ pr\left(0 \xrightarrow{Sr(sff)} i\right)\right\}.\mu_i}{\prod_{k_1 \neq 0} \left\{1 - V_{\overline{k_1 k_1}}\right\}} \right\} \right] \div \left[1 - \sum Sr \left\{ \frac{\left\{ pr\left(0 \xrightarrow{Sr(sff)} 0\right)\right\}}{\prod_{k_2 \neq 0} \left\{1 - V_{\overline{k_2 k_2}}\right\}} \right\} \right]$$

$$T_0 = \frac{U_{0,0}\mu_0 + U_{0,1}\mu_1 + U_{0,2}\mu_2 + U_{0,3}\mu_3}{[1 - (1,0,1)]}$$ (3)

II. Availability of the system

The system is available for use at regenerative states j=0, 1, 2, 3 with ξ=0 then the availability of system is defined as

$$A_0 = \left[\sum_{j=0}^{3} Sr \left\{ \frac{\left\{ pr(0 \xrightarrow{Sr} j) \right\} \cdot f_j \cdot \mu_j}{\Pi_{k_1 \neq 0} \left\{ 1 - V_{\overline{k_1 k_1}} \right\}} \right\} \right] \div \left[\sum_{i=0}^{6} Sr \left\{ \frac{\left\{ pr(0 \xrightarrow{Sr} i) \right\} \cdot \mu_i'}{\Pi_{k_2 \neq 0} \left\{ 1 - V_{\overline{k_2 k_2}} \right\}} \right\} \right]$$

$$A_0 = \frac{U_{0,0}\mu_0 + U_{0,1}\mu_1 + U_{0,2}\mu_2 + U_{0,3}\mu_3}{U_{0,0}\mu_0 + U_{0,1}\mu_1 + U_{0,2}\mu_2 + U_{0,3}\mu_3 + U_{0,4}\mu_4 + U_{0,5}\mu_5 + U_{0,6}\mu_6} \tag{4}$$

III. Busy Period of the Technician

The Technician is busy due to repair of the failed unit at regenerative states j= 1, 2, 3, 4, 5, 6 with ξ = 0 then the fraction of time for which the server remains busy is defined as

$$B_0 = \left[\sum_{j=1}^{6} Sr \left\{ \frac{\left\{ pr(0 \xrightarrow{Sr} j) \right\} \cdot \eta_j}{\Pi_{k_1 \neq 0} \left\{ 1 - V_{\overline{k_1 k_1}} \right\}} \right\} \right] \div \left[\sum_{i=0}^{6} Sr \left\{ \frac{\left\{ pr(0 \xrightarrow{Sr} i) \right\} \cdot \mu_i'}{\Pi_{k_2 \neq 0} \left\{ 1 - V_{\overline{k_2 k_2}} \right\}} \right\} \right]$$

$$B_0 = \frac{U_{0,1}\mu_1 + U_{0,2}\mu_2 + U_{0,3}\mu_3 + U_{0,4}\mu_4 + U_{0,5}\mu_5 + U_{0,6}\mu_6}{U_{0,0}\mu_0 + U_{0,1}\mu_1 + U_{0,2}\mu_2 + U_{0,3}\mu_3 + U_{0,4}\mu_4 + U_{0,5}\mu_5 + U_{0,6}\mu_6} \tag{5}$$

IV. Estimated number of visits made by the Technician

The technician visits at regenerative states j= 1, 2, 3 with ξ=0 then the number of visits by the repairman is defined as

$$V_0 = \left[\sum_{j=1}^{3} Sr \left\{ \frac{\left\{ pr(0 \xrightarrow{Sr} j) \right\}}{\Pi_{k_1 \neq 0} \left\{ 1 - V_{\overline{k_1 k_1}} \right\}} \right\} \right] \div \left[\sum_{i=0}^{6} Sr \left\{ \frac{\left\{ pr(0 \xrightarrow{Sr} i) \right\} \cdot \mu_i'}{\Pi_{k_2 \neq 0} \left\{ 1 - V_{\overline{k_2 k_2}} \right\}} \right\} \right]$$

$$V_0 = \frac{U_{0,1}\mu_1 + U_{0,2}\mu_2 + U_{0,3}\mu_3}{U_{0,0}\mu_0 + U_{0,1}\mu_1 + U_{0,2}\mu_2 + U_{0,3}\mu_3 + U_{0,4}\mu_4 + U_{0,5}\mu_5 + U_{0,6}\mu_6} \tag{6}$$

V. Profit Analysis

The profit values of the juice plant system depend on the system reliability measures such that availability of the system, busy period of the technician, and expected number of visits made by the technician. An expert technician is always available to perform the repair work.

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

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

where, $E_0 = 25000$ (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

Generally, juice plant fulfills the daily requirement of juice as beverage. In the given paper, there are discussed on reliability measures such that tables 2, 3 and 4 describe the nature of mean time to

system failure, availability and profit values of the system under repair facility. It is analyzed that when repair rate enhance from 0.4 to 0.85 then mean time to system failure also enhanced. When failure rate λ_1 change from 0.3 to 0.4, λ_2 changes from 0.4 to 0.5, and λ_3 changes from 0.25 to 0.3 under other parameters as constant then MTSF value decline. It is observed that when repair rate increase (0.4-0.85) then availability values also increased but when λ_1 increase (0.3 to 0.4), λ_2 increase (0.4 to 0.5), and λ_3 increase (0.25 to 0.3) under other parameters as constant then availability values decline.

It is also analyzed that profit values of system are increased with respect to increment in repair rate (0.4-0.85) but decline when failure rate λ_1(0.3 to 0.4), λ_2(0.4 to 0.5), and λ_3(0.25 to 0.3) enhanced under other parameters as constant.

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

w_2 ↓	λ_1=0.3, λ_2=0.4, λ_3=0.25 λ_4=0.35,λ_5=0.5, λ_6=0.55 w_1=0.4, w_3=0.5, w_4=0.5 w_5=0.6, w_6=0.65	λ_1=0.4	λ_2=0.5	λ_3=0.3
0.4	4.76082	4.413408	4.192308	3.96967
0.45	4.929006	4.585448	4.290541	4.045207
0.5	5.063985	4.728682	4.36747	4.103806
0.55	5.174709	4.849785	4.429348	4.150591
0.6	5.267176	4.953519	4.480198	4.188807
0.65	5.345557	5.043371	4.522727	4.220611
0.7	5.412844	5.121951	4.558824	4.247492
0.75	5.471236	5.191257	4.589844	4.27051
0.8	5.522388	5.252838	4.616788	4.290443
0.85	5.567568	5.307918	4.640411	4.307871

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

w_2 ↓	λ_1=0.3, λ_2=0.4 λ_3=0.25, λ_4=0.35 λ_5=0.5, λ_6=0.55 w_1=0.4 w_3=0.5, w_4=0.5 w_5=0.6, w_6=0.65	λ_1=0.4	λ_2=0.5	λ_2=0.3
0.4	0.686403	0.670466	0.657986	0.648775
0.45	0.69355	0.678566	0.662905	0.638243
0.5	0.699041	0.684997	0.666652	0.630578
0.55	0.703393	0.690227	0.669601	0.624746
0.6	0.706926	0.694563	0.671982	0.620162
0.65	0.709852	0.698216	0.673945	0.616462
0.7	0.712315	0.701336	0.675592	0.613414
0.75	0.714416	0.704032	0.676992	0.610865
0.8	0.716231	0.706384	0.678198	0.608687
0.85	0.717813	0.708454	0.679247	0.606818

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

w_2 ↓	λ_1=0.3, λ_2=0.4 λ_3=0.25, λ_4=0.35 λ_5=0.5, λ_6=0.55 w_1=0.4 w_3=0.5, w_4=0.5 w_5=0.6, w_6=0.65	λ_1=0.4	λ_2=0.5	λ_2=0.3
0.5	2722.902	2572.193	2533.318	2459.635
0.55	2788.908	2650.579	2583.419	2428.449
0.6	2838.719	2711.387	2620.861	2405.743
0.65	2877.66	2759.963	2649.913	2388.471
0.7	2908.947	2799.676	2673.117	2374.89
0.75	2934.638	2832.757	2692.08	2363.932
0.8	2956.115	2860.746	2707.868	2354.904
0.85	2974.335	2884.737	2721.218	2347.337
0.9	2989.99	2905.531	2732.655	2340.903
0.95	3003.585	2923.73	2742.563	2335.365

IX. Comparative study

Comparative study of juice plants described that mean time to system failure, availability of the system, and profit values of juice plant-I are greater than corresponding values of juice plant-II. In juice plant-I, mean time to system failure lowest value is 3.96967 and highest value is 5.567568 but in juice plant-II, its lowest value is3.037974 and highest value is 4.019608.

In juice plant-I, availability lie between (0.648775 - 0.717813) but in juice plant-II, it lie between (0.58624-0.663876). The profit values of juice plant-I exists from 2459.63 to 3003.585 but in juice plant –II, it exists from 2333.81 to 2673.74.

X. Conclusion

The performance of the juice plant 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.

It is observed that the role of the regenerative point graphical technique for the juice plant 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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